Developer Manual V2.8.3, 2022-08-09

Contents

Chapter 1

Introduction

This handbook is a work in progress. If you are able to help with writing, editing, or graphic preparation please contact any member of the writing team or join and send an email to emc-users@lists.sourceforge.net.

Chapter 2

Code Notes

2.1 Intended audience

This document is a collection of notes about the internals of LinuxCNC. It is primarily of interest to developers, however much of the information here may also be of interest to system integrators and others who are simply curious about how LinuxCNC works. Much of this information is now outdated and has never been reviewed for accuracy.

2.2 Organization

There will be a chapter for each of the major components of LinuxCNC, as well as chapter(s) covering how they work together. This document is very much a work in progress, and its layout may change in the future.

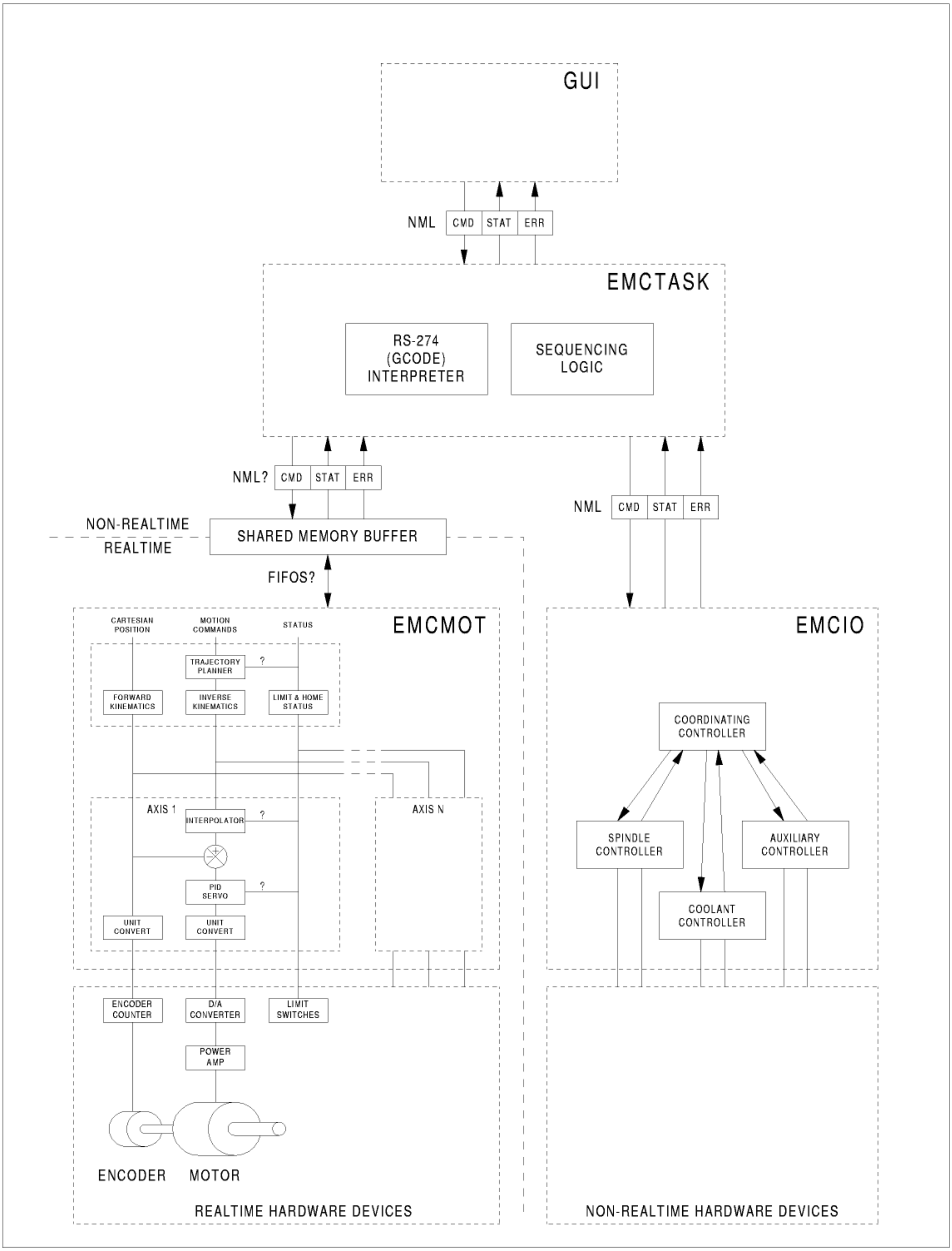
2.3 Terms and definitions

- *AXIS* - An axis is one of the nine degrees of freedom that define a tool position in three-dimensional Cartesian space. Those nine axes are referred to as X, Y, Z, A, B, C, U, V, and W. The linear orthagonal coordinates X, Y, and Z determine where the tip of the tool is positioned. The angular coordinates A, B, and C determine the tool orientation. A second set of linear orthagonal coordinates U, V, and W allows tool motion (typically for cutting actions) relative to the previously offset and rotated axes. Unfortunately "axis" is also sometimes used to mean a degree of freedom of the machine itself, such as the saddle, table, or quill of a Bridgeport type milling machine. On a Bridgeport this causes no confusion, since movement of the table directly corresponds to movement along the X axis. However, the shoulder and elbow joints of a robot arm and the linear actuators of a hexapod do not correspond to movement along any Cartesian axis, and in general it is important to make the distinction between the Cartesian axes and the machine degrees of freedom. In this document, the latter will be called *joints*, not axes. (The GUIs and some other parts of the code may not always follow this distinction, but the internals of the motion controller do.)
- *JOINT* - A joint is one of the movable parts of the machine. Joints are distinct from axes, although the two terms are sometimes (mis)used to mean the same thing. In LinuxCNC, a joint is a physical thing that can be moved, not a coordinate in space. For example, the quill, knee, saddle, and table of a Bridgeport mill are all joints. The shoulder, elbow, and wrist of a robot arm are joints, as are the linear actuators of a hexapod. Every joint has a motor or actuator of some type associated with it. Joints do not necessarily correspond to the X, Y, and Z axes, although for machines with trivial kinematics that may be the case. Even on those machines, joint position and axis position are fundamentally different things. In this document, the terms *joint* and *axis* are used carefully to respect their distinct meanings. Unfortunately that isn't necessarily true everywhere else. In particular, GUIs for machines with trivial kinematics may gloss over or completely hide the distinction between joints and axes. In addition, the ini file uses the term *axis* for data that would more accurately be described as joint data, such as input and output scaling, etc.

- *POSE* - A pose is a fully specified position in 3-D Cartesian space. In the LinuxCNC motion controller, when we refer to a pose we mean an EmcPose structure, containing six linear coordinates (X, Y, Z, U, V, and W) and three angular ones (A, B, and C).

2.4 Architecture overview

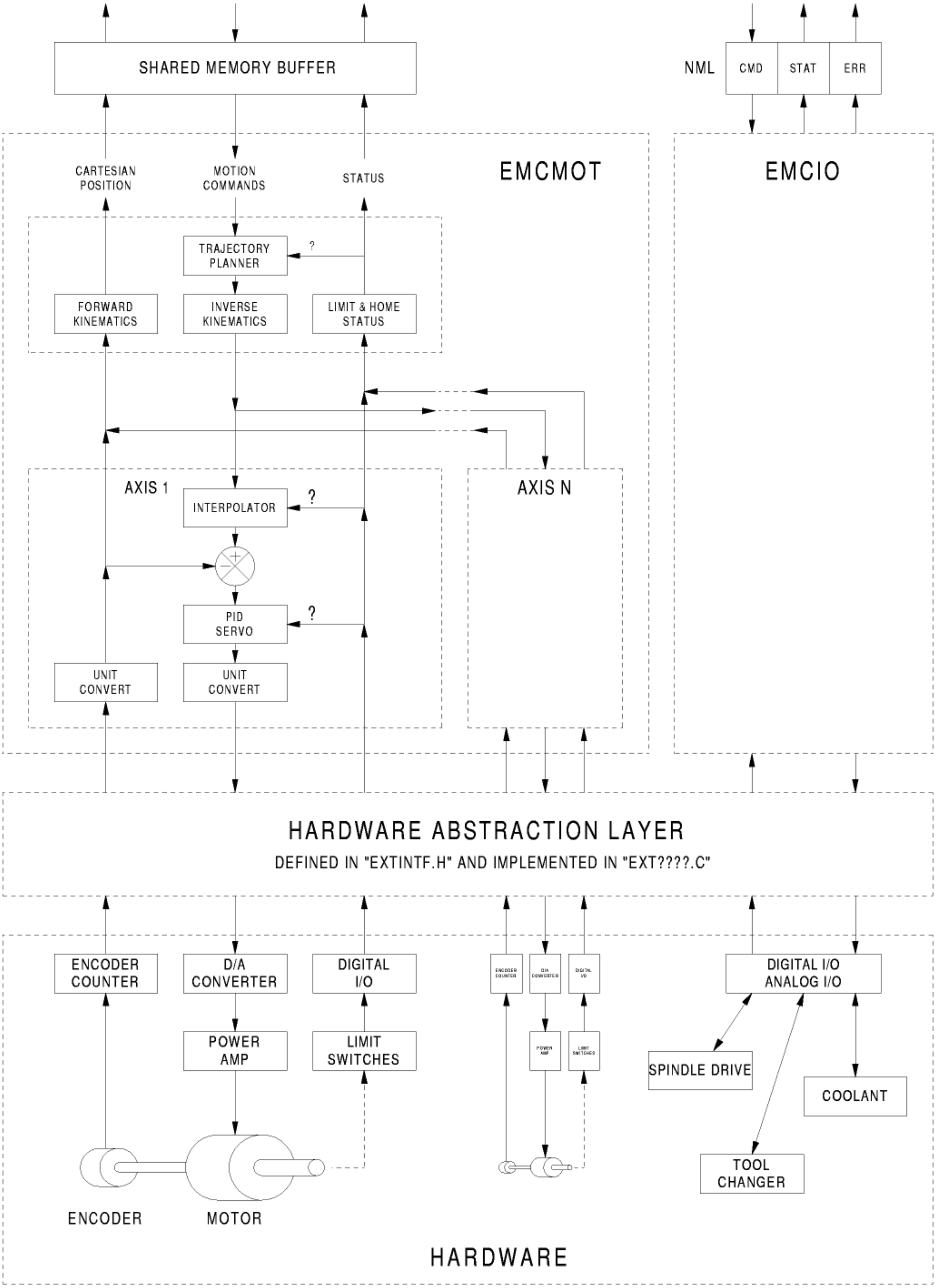
There are four components contained in the LinuxCNC Architecture: a motion controller (EMCMOT), a discrete IO controller (EMCIO), a task executor which coordinates them (EMCTASK) and several text-mode and graphical User Interfaces. Each of them will be described in the current document, both from the design point of view and from the developers point of view (where to find needed data, how to easily extend/modify things, etc.).


GUI
NML
CMD
STAT
ERR
EMCTASK
RS-274 (GCODE) INTERPRETER
SEQUENCING LOGIC
NML?
CMD
STAT
ERR
NML
CMD
STAT
ERR
NON-REALTIME
REALTIME
SHARED MEMORY BUFFER
FIFOS?
EMCMOT
CARTESIAN POSITION
MOTION COMMANDS
STATUS
TRAJECTORY PLANNER
?
FORWARD KINEMATICS
INVERSE KINEMATICS
LIMIT & HOME STATUS
AXIS 1
INTERPOLATOR
?
PID SERVO
?
UNIT CONVERT
UNIT CONVERT
AXIS N
EMCIO
COORDINATING CONTROLLER
SPINDLE CONTROLLER
AUXILIARY CONTROLLER
COOLANT CONTROLLER
ENCODER COUNTER
D/A CONVERTER
LIMIT SWITCHES
POWER AMP
ENCODER
MOTOR
REALTIME HARDWARE DEVICES
NON-REALTIME HARDWARE DEVICES

LinuxCNC software architecture. At the coarsest level, LinuxCNC is a hierarchy of three controllers: the task level command handler and program interpreter, the motion controller, and the discrete I/O controller. The discrete I/O controller is implemented as a hierarchy of controllers, in this case for spindle, coolant, and auxiliary (e.g., estop, lube) subsystems. The task controller coordinates the actions of the motion and discrete I/O controllers. Their actions are programmed in conventional numerical control "G and M code" programs, which are interpreted by the task controller into NML messages and sent to either the motion or discrete I/O controllers at the appropriate times.

2.5 Motion Controller Introduction

The motion controller receives commands from user space modules via a shared memory buffer, and executes those commands in realtime. The status of the controller is made available to the user space modules through the same shared memory area. The motion controller interacts with the motors and other hardware using the HAL (Hardware Abstraction Layer). This document assumes that the reader has a basic understanding of the HAL, and uses terms like HAL pins, HAL signals, etc, without explaining them. For more information about the HAL, see the HAL Manual. Another chapter of this document will eventually go into the internals of the HAL itself, but in this chapter, we only use the HAL API as defined in src/hal/hal.h.



SHARED MEMORY BUFFER
NML
CMD
STAT
ERR
CARTESIAN POSITION
MOTION COMMANDS
STATUS
EMCMOT
EMCIO
TRAJECTORY PLANNER
?
FORWARD KINEMATICS
INVERSE KINEMATICS
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AXIS 1
AXIS N
INTERPOLATOR
?
PID SERVO
?
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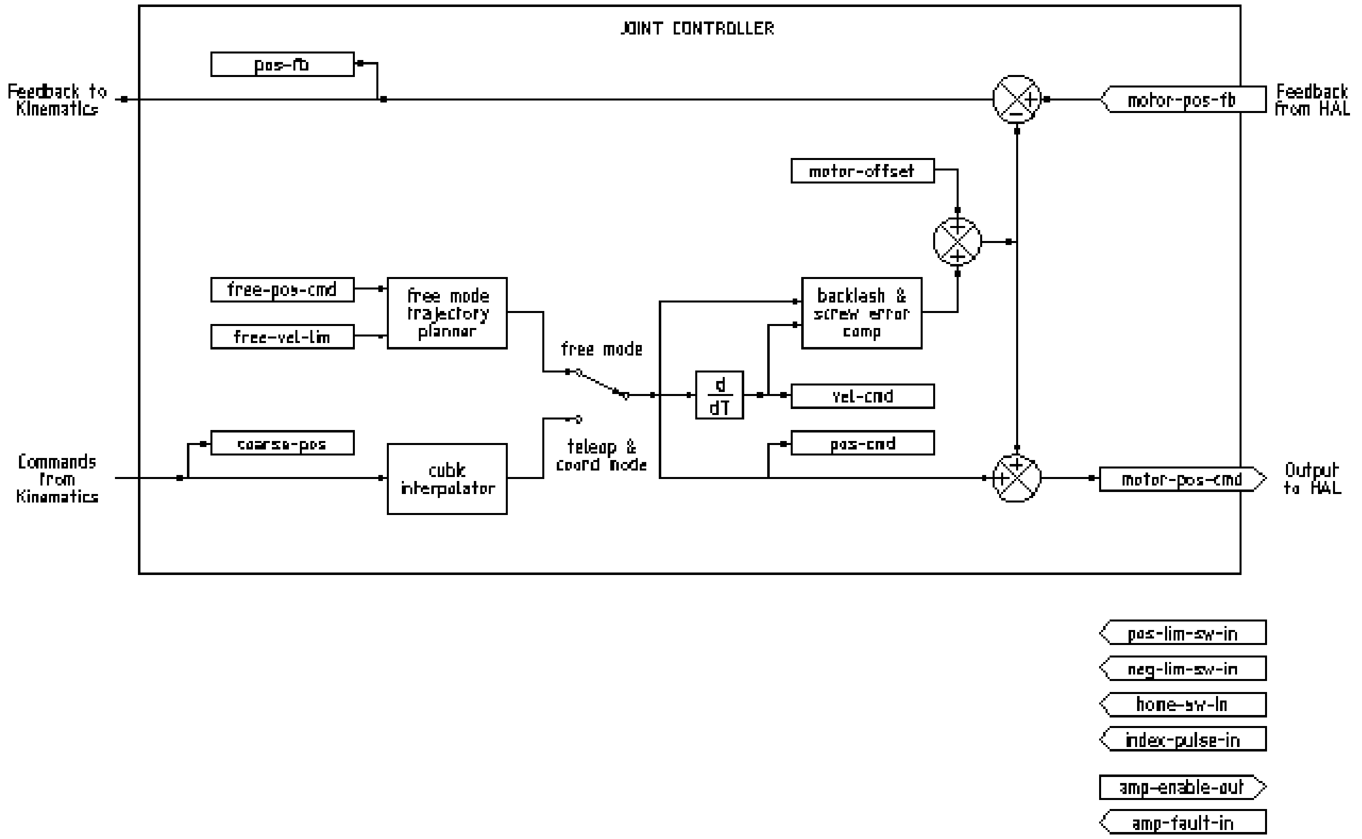
HARDWARE ABSTRACTION LAYER
DEFINED IN "EXTINTF.H" AND IMPLEMENTED IN "EXT????.C"
ENCODER COUNTER
D/A CONVERTER
DIGITAL I/O
DIGITAL I/O ANALOG I/O
POWER AMP
LIMIT SWITCHES
SPINDLE DRIVE
COOLANT
TOOL CHANGER
ENCODER
MOTOR
HARDWARE

2.6 Block diagrams and Data Flow

The following figure is a block diagram of a joint controller. There is one joint controller per joint. The joint controllers work at a lower level than the kinematics, a level where all joints are completely independent. All the data for a joint is in a single joint structure. Some members of that structure are visible in the block diagram, such as coarse_pos, pos_cmd, and motor_pos_fb.



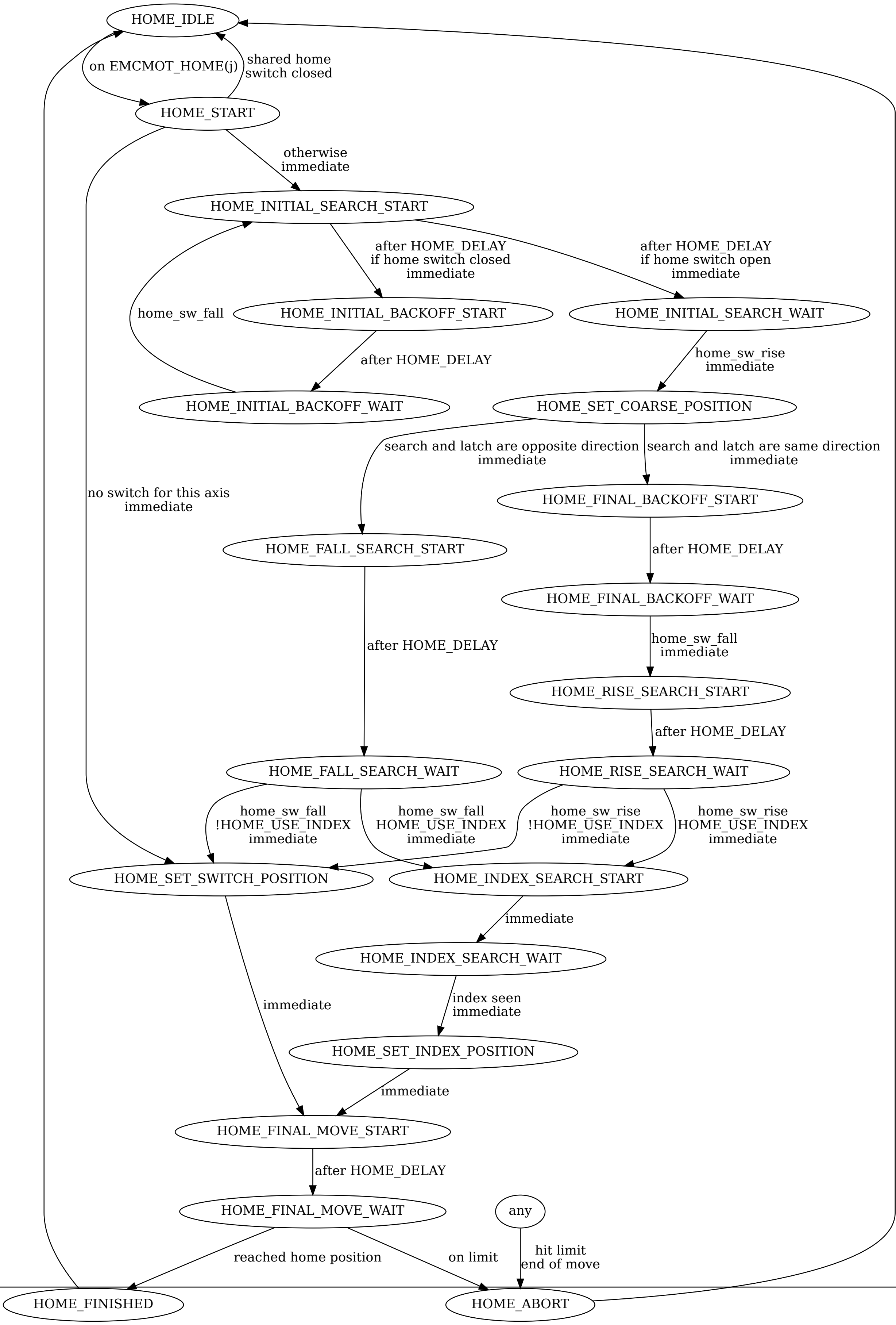
Joint Controller Block Diagram The above figure shows five of the seven sets of position information that form the main data flow through the motion controller. The seven forms of position data are as follows:

1. *emcmotStatus->carte_pos_cmd* - This is the desired position, in Cartesian coordinates. It is updated at the traj rate, not the servo rate. In coord mode, it is determined by the traj planner. In teleop mode, it is determined by the traj planner? In free mode, it is either copied from actualPos, or generated by applying forward kins to (2) or (3).
2. *emcmotStatus->joints[n].coarse_pos* - This is the desired position, in joint coordinates, but before interpolation. It is updated at the traj rate, not the servo rate. In coord mode, it is generated by applying inverse kins to (1) In teleop mode, it is generated by applying inverse kins to (1) In free mode, it is copied from (3), I think.
3. ’emcmotStatus->joints[n].pos_cmd - This is the desired position, in joint coords, after interpolation. A new set of these coords is generated every servo period. In coord mode, it is generated from (2) by the interpolator. In teleop mode, it is generated from (2) by the interpolator. In free mode, it is generated by the free mode traj planner.
4. *emcmotStatus->joints[n].motor_pos_cmd* - This is the desired position, in motor coords. Motor coords are generated by adding backlash compensation, lead screw error compensation, and offset (for homing) to (3). It is generated the same way regardless of the mode, and is the output to the PID loop or other position loop.

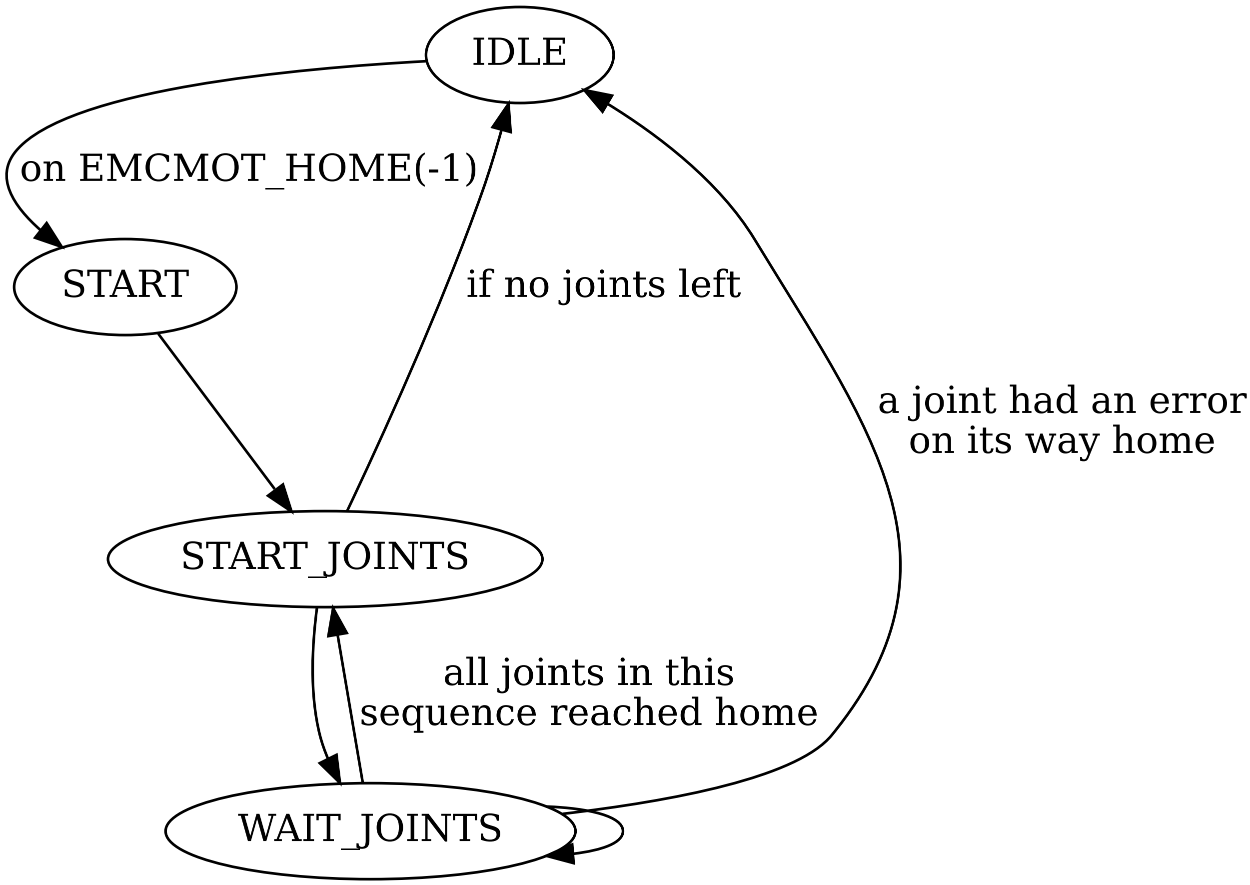
5. *emcmotStatus->joints[n].motor_pos_fb* - This is the actual position, in motor coords. It is the input from encoders or other feedback device (or from virtual encoders on open loop machines). It is "generated" by reading the feedback device.
6. *emcmotStatus->joints[n].pos_fb* - This is the actual position, in joint coordinates. It is generated by subtracting offset, lead screw error compensation, and backlash compensation from (5). It is generated the same way regardless of the operating mode.
7. *emcmotStatus->carte_pos_fb* - This is the actual position, in Cartesian coordinates. It is updated at the traj rate, not the servo rate. Ideally, actualPos would always be calculated by applying forward kinematics to (6). However, forward kinematics may not be available, or they may be unusable because one or more axes aren't homed. In that case, the options are: A) fake it by copying (1), or B) admit that we don't really know the Cartesian coordinates, and simply don't update actualPos. Whatever approach is used, I can see no reason not to do it the same way regardless of the operating mode. I would propose the following: If there are forward kins, use them, unless they don't work because of unhomed axes or other problems, in which case do (B). If no forward kins, do (A), since otherwise actualPos would *never* get updated.

2.7 Homing

2.7.1 Homing state diagram



2.7.2 Another homing diagram



2.8 Commands

This section simply lists all of the commands that can be sent to the motion module, along with detailed explanations of what they do. The command names are defined in a large typedef enum in code, each command name starts with *EMCMOT_*, which is omitted here.)

The commands are implemented by a large switch statement in the function emcmotCommandHandler(), which is called at the servo rate. More on that function later.

There are approximately 44 commands - this list is still under construction.

2.8.1 ABORT

The ABORT command simply stops all motion. It can be issued at any time, and will always be accepted. It does not disable the motion controller or change any state information, it simply cancels any motion that is currently in progress.[1]

2.8.1.1 Requirements

None. The command is always accepted and acted on immediately.

[1] It seems that the higher level code (TASK and above) also use ABORT to clear faults. Whenever there is a persistent fault (such as being outside the hardware limit switches), the higher level code sends a constant stream of ABORTs to the motion controller trying to make the fault go away. Thousands of 'em. . . . That means that the motion controller should avoid persistent faults. This needs to be looked into.

2.8.1.2 Results

In free mode, the free mode trajectory planners are disabled. That results in each joint stopping as fast as its accel (decel) limit allows. The stop is not coordinated. In teleop mode, the commanded Cartesian velocity is set to zero. I don't know exactly what kind of stop results (coordinated, uncoordinated, etc), but will figure it out eventually. In coord mode, the coord mode trajectory planner is told to abort the current move. Again, I don't know the exact result of this, but will document it when I figure it out.

2.8.2 FREE

The FREE command puts the motion controller in free mode. Free mode means that each joint is independent of all the other joints. Cartesian coordinates, poses, and kinematics are ignored when in free mode. In essence, each joint has its own simple trajectory planner, and each joint completely ignores the other joints. Some commands (like Joint JOG and HOME) only work in free mode. Other commands, including anything that deals with Cartesian coordinates, do not work at all in free mode.

2.8.2.1 Requirements

The command handler applies no requirements to the FREE command, it will always be accepted. However, if any joint is in motion (GET_MOTION_INPOS_FLAG() == FALSE), then the command will be ignored. This behavior is controlled by code that is now located in the function *set_operating_mode()* in control.c, that code needs to be cleaned up. I believe the command should not be silently ignored, instead the command handler should determine whether it can be executed and return an error if it cannot.

2.8.2.2 Results

If the machine is already in free mode, nothing. Otherwise, the machine is placed in free mode. Each joint's free mode trajectory planner is initialized to the current location of the joint, but the planners are not enabled and the joints are stationary.

2.8.3 TELEOP

The TELEOP command places the machine in teleoperating mode. In teleop mode, movement of the machine is based on Cartesian coordinates using kinematics, rather than on individual joints as in free mode. However the trajectory planner per se is not used, instead movement is controlled by a velocity vector. Movement in teleop mode is much like jogging, except that it is done in Cartesian space instead of joint space. On a machine with trivial kinematics, there is little difference between teleop mode and free mode, and GUIs for those machines might never even issue this command. However for non-trivial machines like robots and hexapods, teleop mode is used for most user commanded jog type movements.

2.8.3.1 Requirements

The command handler will reject the TELEOP command with an error message if the kinematics cannot be activated because the one or more joints have not been homed. In addition, if any joint is in motion (GET_MOTION_INPOS_FLAG() == FALSE), then the command will be ignored (with no error message). This behavior is controlled by code that is now located in the function *set_operating_mode()* in control.c. I believe the command should not be silently ignored, instead the command handler should determine whether it can be executed and return an error if it cannot.

2.8.3.2 Results

If the machine is already in teleop mode, nothing. Otherwise the machine is placed in teleop mode. The kinematics code is activated, interpolators are drained and flushed, and the Cartesian velocity commands are set to zero.

2.8.4 COORD

The COORD command places the machine in coordinated mode. In coord mode, movement of the machine is based on Cartesian coordinates using kinematics, rather than on individual joints as in free mode. In addition, the main trajectory planner is used to generate motion, based on queued LINE, CIRCLE, and/or PROBE commands. Coord mode is the mode that is used when executing a G-code program.

2.8.4.1 Requirements

The command handler will reject the COORD command with an error message if the kinematics cannot be activated because the one or more joints have not been homed. In addition, if any joint is in motion (GET_MOTION_INPOS_FLAG() == FALSE), then the command will be ignored (with no error message). This behavior is controlled by code that is now located in the function *set_operating_mode()* in control.c. I believe the command should not be silently ignored, instead the command handler should determine whether it can be executed and return an error if it cannot.

2.8.4.2 Results

If the machine is already in coord mode, nothing. Otherwise, the machine is placed in coord mode. The kinematics code is activated, interpolators are drained and flushed, and the trajectory planner queues are empty. The trajectory planner is active and awaiting a LINE, CIRCLE, or PROBE command.

2.8.5 ENABLE

The ENABLE command enables the motion controller.

2.8.5.1 Requirements

None. The command can be issued at any time, and will always be accepted.

2.8.5.2 Results

If the controller is already enabled, nothing. If not, the controller is enabled. Queues and interpolators are flushed. Any movement or homing operations are terminated. The amp-enable outputs associated with active joints are turned on. If forward kinematics are not available, the machine is switched to free mode.

2.8.6 DISABLE

The DISABLE command disables the motion controller.

2.8.6.1 Requirements

None. The command can be issued at any time, and will always be accepted.

2.8.6.2 Results

If the controller is already disabled, nothing. If not, the controller is disabled. Queues and interpolators are flushed. Any movement or homing operations are terminated. The amp-enable outputs associated with active joints are turned off. If forward kinematics are not available, the machine is switched to free mode.

2.8.7 ENABLE_AMPLIFIER

The ENABLE_AMPLIFIER command turns on the amp enable output for a single output amplifier, without changing anything else. Can be used to enable a spindle speed controller.

2.8.7.1 Requirements

None. The command can be issued at any time, and will always be accepted.

2.8.7.2 Results

Currently, nothing. (A call to the old extAmpEnable function is currently commented out.) Eventually it will set the amp enable HAL pin true.

2.8.8 DISABLE_AMPLIFIER

The DISABLE_AMPLIFIER command turns off the amp enable output for a single amplifier, without changing anything else. Again, useful for spindle speed controllers.

2.8.8.1 Requirements

None. The command can be issued at any time, and will always be accepted.

2.8.8.2 Results

Currently, nothing. (A call to the old extAmpEnable function is currently commented out.) Eventually it will set the amp enable HAL pin false.

2.8.9 ACTIVATE_JOINT

The ACTIVATE_JOINT command turns on all the calculations associated with a single joint, but does not change the joint's amp enable output pin.

2.8.9.1 Requirements

None. The command can be issued at any time, and will always be accepted.

2.8.9.2 Results

Calculations for the specified joint are enabled. The amp enable pin is not changed, however, any subsequent ENABLE or DISABLE commands will modify the joint's amp enable pin.

2.8.10 DEACTIVATE_JOINT

The DEACTIVATE_JOINT command turns off all the calculations associated with a single joint, but does not change the joint's amp enable output pin.

2.8.10.1 Requirements

None. The command can be issued at any time, and will always be accepted.

2.8.10.2 Results

Calculations for the specified joint are enabled. The amp enable pin is not changed, and subsequent ENABLE or DISABLE commands will not modify the joint's amp enable pin.

2.8.11 ENABLE_WATCHDOG

The ENABLE_WATCHDOG command enables a hardware based watchdog (if present).

2.8.11.1 Requirements

None. The command can be issued at any time, and will always be accepted.

2.8.11.2 Results

Currently nothing. The old watchdog was a strange thing that used a specific sound card. A new watchdog interface may be designed in the future.

2.8.12 DISABLE_WATCHDOG

The DISABLE_WATCHDOG command disables a hardware based watchdog (if present).

2.8.12.1 Requirements

None. The command can be issued at any time, and will always be accepted.

2.8.12.2 Results

Currently nothing. The old watchdog was a strange thing that used a specific sound card. A new watchdog interface may be designed in the future.

2.8.13 PAUSE

The PAUSE command stops the trajectory planner. It has no effect in free or teleop mode. At this point I don't know if it pauses all motion immediately, or if it completes the current move and then pauses before pulling another move from the queue.

2.8.13.1 Requirements

None. The command can be issued at any time, and will always be accepted.

2.8.13.2 Results

The trajectory planner pauses.

2.8.14 RESUME

The RESUME command restarts the trajectory planner if it is paused. It has no effect in free or teleop mode, or if the planner is not paused.

2.8.14.1 Requirements

None. The command can be issued at any time, and will always be accepted.

2.8.14.2 Results

The trajectory planner resumes.

2.8.15 STEP

The STEP command restarts the trajectory planner if it is paused, and tells the planner to stop again when it reaches a specific point. It has no effect in free or teleop mode. At this point I don't know exactly how this works. I'll add more documentation here when I dig deeper into the trajectory planner.

2.8.15.1 Requirements

None. The command can be issued at any time, and will always be accepted.

2.8.15.2 Results

The trajectory planner resumes, and later pauses when it reaches a specific point.

2.8.16 SCALE

The SCALE command scales all velocity limits and commands by a specified amount. It is used to implement feed rate override and other similar functions. The scaling works in free, teleop, and coord modes, and affects everything, including homing velocities, etc. However, individual joint velocity limits are unaffected.

2.8.16.1 Requirements

None. The command can be issued at any time, and will always be accepted.

2.8.16.2 Results

All velocity commands are scaled by the specified constant.

2.8.17 OVERRIDE_LIMITS

The OVERRIDE_LIMITS command prevents limits from tripping until the end of the next JOG command. It is normally used to allow a machine to be jogged off of a limit switch after tripping. (The command can actually be used to override limits, or to cancel a previous override.)

2.8.17.1 Requirements

None. The command can be issued at any time, and will always be accepted. (I think it should only work in free mode.)

2.8.17.2 Results

Limits on all joints are over-ridden until the end of the next JOG command. (This is currently broken… once an OVERRIDE_LIMITS command is received, limits are ignored until another OVERRIDE_LIMITS command re-enables them.)

2.8.18 HOME

The HOME command initiates a homing sequence on a specified joint. The actual homing sequence is determined by a number of configuration parameters, and can range from simply setting the current position to zero, to a multi-stage search for a home switch and index pulse, followed by a move to an arbitrary home location. For more information about the homing sequence, see the homing section of the Integrator Manual.

2.8.18.1 Requirements

The command will be ignored silently unless the machine is in free mode.

2.8.18.2 Results

Any jog or other joint motion is aborted, and the homing sequence starts.

2.8.19 JOG_CONT

The JOG_CONT command initiates a continuous jog on a single joint. A continuous jog is generated by setting the free mode trajectory planner's target position to a point beyond the end of the joint's range of travel. This ensures that the planner will move constantly until it is stopped by either the joint limits or an ABORT command. Normally, a GUI sends a JOG_CONT command when the user presses a jog button, and ABORT when the button is released.

2.8.19.1 Requirements

The command handler will reject the JOG_CONT command with an error message if machine is not in free mode, or if any joint is in motion (GET_MOTION_INPOS_FLAG() == FALSE), or if motion is not enabled. It will also silently ignore the command if the joint is already at or beyond its limit and the commanded jog would make it worse.

2.8.19.2 Results

The free mode trajectory planner for the joint identified by emcmotCommand->axis is activated, with a target position beyond the end of joint travel, and a velocity limit of emcmotCommand->vel. This starts the joint moving, and the move will continue until stopped by an ABORT command or by hitting a limit. The free mode planner accelerates at the joint accel limit at the beginning of the move, and will decelerate at the joint accel limit when it stops.

2.8.20 JOG_INCR

The JOG_INCR command initiates an incremental jog on a single joint. Incremental jogs are cumulative, in other words, issuing two JOG_INCR commands that each ask for 0.100 inches of movement will result in 0.200 inches of travel, even if the second command is issued before the first one finishes. Normally incremental jogs stop when they have traveled the desired distance, however they also stop when they hit a limit, or on an ABORT command.

2.8.20.1 Requirements

The command handler will silently reject the JOG_INCR command if machine is not in free mode, or if any joint is in motion (GET_MOTION_INPOS_FLAG() == FALSE), or if motion is not enabled. It will also silently ignore the command if the joint is already at or beyond its limit and the commanded jog would make it worse.

2.8.20.2 Results

The free mode trajectory planner for the joint identified by emcmotCommand->axis is activated, the target position is incremented/decremented by emcmotCommand->offset, and the velocity limit is set to emcmotCommand->vel. The free mode trajectory planner will generate a smooth trapezoidal move from the present position to the target position. The planner can correctly handle changes in the target position that happen while the move is in progress, so multiple JOG_INCR commands can be issued in quick succession. The free mode planner accelerates at the joint accel limit at the beginning of the move, and will decelerate at the joint accel limit to stop at the target position.

2.8.21 JOG_ABS

The JOG_ABS command initiates an absolute jog on a single joint. An absolute jog is a simple move to a specific location, in joint coordinates. Normally absolute jogs stop when they reach the desired location, however they also stop when they hit a limit, or on an ABORT command.

2.8.21.1 Requirements

The command handler will silently reject the JOG_ABS command if machine is not in free mode, or if any joint is in motion (GET_MOTION_INPOS_FLAG() == FALSE), or if motion is not enabled. It will also silently ignore the command if the joint is already at or beyond its limit and the commanded jog would make it worse.

2.8.21.2 Results

The free mode trajectory planner for the joint identified by emcmotCommand->axis is activated, the target position is set to emcmotCommand->offset, and the velocity limit is set to emcmotCommand->vel. The free mode trajectory planner will generate a smooth trapezoidal move from the present position to the target position. The planner can correctly handle changes in the target position that happen while the move is in progress. If multiple JOG_ABS commands are issued in quick succession, each new command changes the target position and the machine goes to the final commanded position. The free mode planner accelerates at the joint accel limit at the beginning of the move, and will decelerate at the joint accel limit to stop at the target position.

2.8.22 SET_LINE

The SET_LINE command adds a straight line to the trajectory planner queue.

(More later)

2.8.23 SET_CIRCLE

The SET_CIRCLE command adds a circular move to the trajectory planner queue.

(More later)

2.8.24 SET_TELEOP_VECTOR

The SET_TELEOP_VECTOR command instructs the motion controller to move along a specific vector in Cartesian space.

(More later)

2.8.25 PROBE

The PROBE command instructs the motion controller to move toward a specific point in Cartesian space, stopping and recording its position if the probe input is triggered.

(More later)

2.8.26 CLEAR_PROBE_FLAG

The CLEAR_PROBE_FLAG command is used to reset the probe input in preparation for a PROBE command. (Question: why shouldn't the PROBE command automatically reset the input?)

(More later)

2.8.27 SET_xix

There are approximately 15 SET_xxx commands, where xxx is the name of some configuration parameter. It is anticipated that there will be several more SET commands as more parameters are added. I would like to find a cleaner way of setting and reading configuration parameters. The existing methods require many lines of code to be added to multiple files each time a parameter is added. Much of that code is identical or nearly identical for every parameter.

2.9 Backlash and Screw Error Compensation

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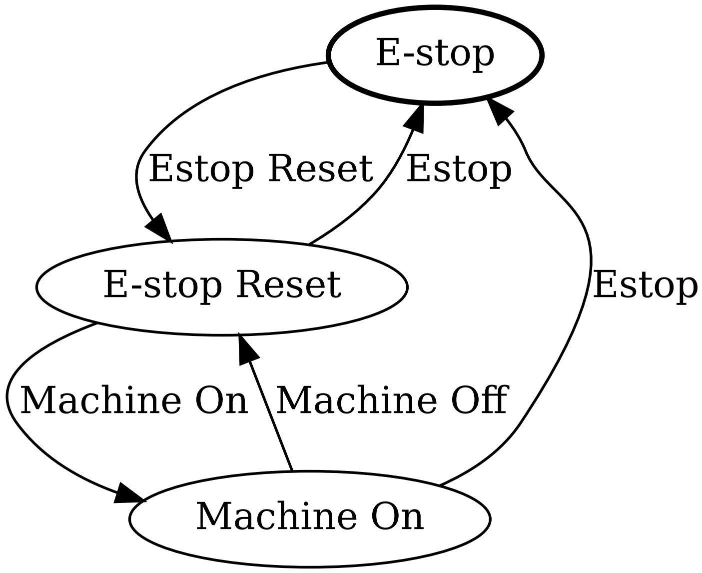
2.10 Task controller (EMCTASK)

2.10.1 State

Task has three possible internal states: **E-stop**, **E-stop Reset**, and **Machine On**.



2.11 IO controller (EMCIO)

The I/O Controller is separate module that accepts NML commands from TASK.
It interacts with external I/O using HAL pins.
iocontrol.cc is loaded via the linuxcnc script before TASK is.
There are curently two versions of iocontrol. The second version handles toolchange hardware errors

Curently ESTOP/Enable, coolant, lube, and tool changing are handled by
iocontrol. These are relatively low speed events, high speed coordinated I/O is handled in motion.

emctaskmain.cc sends I/O commands via taskclass.cc
Taskclass's functions send NML messages out to iocontrol.cc
taskclass either uses the commands defined in c++ in it's file or,
if defined, runs python based commands defined in files provided by the user.

iocontrol main loop process:

- registers for SIGTERM and SIGINT signals from the OS.
- checks to see it HAL inputs have changed
- checks if read_tool_inputs() indicates the tool change is finished and set emcioStatus.status
- checks for I/O related NML messages

nml message numbers: from emc.hh:

#define EMC_IO_INIT_TYPE ((NMLTYPE) 1601)
#define EMC_TOOL_STAT_TYPE ((NMLTYPE) 1199)
#define EMC_TOOL_INIT_TYPE ((NMLTYPE) 1101)
#define EMC_TOOL_HALT_TYPE ((NMLTYPE) 1102)
#define EMC_TOOL_ABORT_TYPE ((NMLTYPE) 1103)
#define EMC_TOOL_PREPARE_TYPE ((NMLTYPE) 1104)
#define EMC_TOOL_LOAD_TYPE ((NMLTYPE) 1105)
#define EMC_TOOL_UNLOAD_TYPE ((NMLTYPE) 1106)
#define EMC_TOOL_LOAD_TOOL_TABLE_TYPE ((NMLTYPE) 1107)
#define EMC_TOOL_SET_OFFSET_TYPE ((NMLTYPE) 1108)
#define EMC_TOOL_SET_NUMBER_TYPE ((NMLTYPE) 1109)
#define EMC_TOOL_START_CHANGE_TYPE ((NMLTYPE) 1110)

2.12 User Interfaces

+

2.13 libnml Introduction

libnml is derived from the NIST rcslib without all the multi-platform support. Many of the wrappers around platform specific code has been removed along with much of the code that is not required by LinuxCNC. It is hoped that sufficient compatibility remains with rcslib so that applications can be implemented on non-Linux platforms and still be able to communicate with LinuxCNC.

This chapter is not intended to be a definitive guide to using libnml (or rcslib), instead, it will eventually provide an overview of each C++ class and their member functions. Initially, most of these notes will be random comments added as the code scrutinized and modified.

2.14 LinkedList

Base class to maintain a linked list. This is one of the core building blocks used in passing NML messages and assorted internal data structures.

2.15 LinkedListNode

Base class for producing a linked list - Purpose, to hold pointers to the previous and next nodes, pointer to the data, and the size of the data.

No memory for data storage is allocated.

2.16 SharedMemory

Provides a block of shared memory along with a semaphore (inherited from the Semaphore class). Creation and destruction of the semaphore is handled by the SharedMemory constructor and destructor.

2.17 ShmBuffer

Class for passing NML messages between local processes using a shared memory buffer. Much of internal workings are inherited from the CMS class.

2.18 Timer

The Timer class provides a periodic timer limited only by the resolution of the system clock. If, for example, a process needs to be run every 5 seconds regardless of the time taken to run the process, the following code snippet demonstrates how :

```
main()
{
    timer = new Timer(5.0);    /* Initialize a timer with a 5 second loop */
    while(0) {
        /* Do some process */
        timer.wait();    /* Wait till the next 5 second interval */
    }
    delete timer;
}
```

2.19 Semaphore

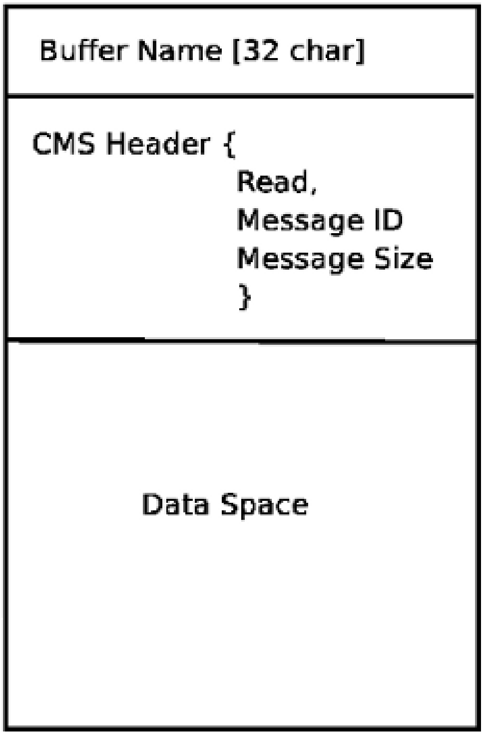
The Semaphore class provides a method of mutual exclusions for accessing a shared resource. The function to get a semaphore can either block until access is available, return after a timeout, or return immediately with or without gaining the semaphore. The constructor will create a semaphore or attach to an existing one if the ID is already in use.

The Semaphore::destroy() must be called by the last process only.

2.20 CMS

At the heart of libnml is the CMS class, it contains most of the functions used by libnml and ultimately NML. Many of the internal functions are overloaded to allow for specific hardware dependent methods of data passing. Ultimately, everything revolves around a central block of memory (referred to as the *message buffer* or just *buffer*). This buffer may exist as a shared memory block accessed by other CMS/NML processes, or a local and private buffer for data being transferred by network or serial interfaces.

The buffer is dynamically allocated at run time to allow for greater flexibility of the CMS/NML sub-system. The buffer size must be large enough to accommodate the largest message, a small amount for internal use and allow for the message to be encoded if this option is chosen (encoded data will be covered later). The following figure is an internal view of the buffer space.



CMS buffer The CMS base class is primarily responsible for creating the communications pathways and interfacing to the O.S.

2.21 Configuration file format

NML configuration consists of two types of line formats. One for Buffers, and a second for Processes that connect to the buffers.

2.21.1 Buffer line

The original NIST format of the buffer line is:

- *B name type host size neut RPC# buffer# max_procs key [type specific configs]*
- *B* - identifies this line as a Buffer configuration.
- *name* - is the identifier of the buffer.
- *type* - describes the buffer type - SHMEM, LOCMEM, FILEMEM, PHANTOM, or GLOBMEM.
- *host* - is either an IP address or host name for the NML server

- *size* - is the size of the buffer
- *neut* - a boolean to indicate if the data in the buffer is encoded in a machine independent format, or raw.
- *RPC#* - Obsolete - Place holder retained for backward compatibility only.
- *buffer#* - A unique ID number used if a server controls multiple buffers.
- *max_procs* - is the maximum processes allowed to connect to this buffer.
- *key* - is a numerical identifier for a shared memory buffer

2.21.2 Type specific configs

The buffer type implies additional configuration options whilst the host operating system precludes certain combinations. In an attempt to distill published documentation in to a coherent format, only the **SHMEM** buffer type will be covered.

- *mutex=os_sem* - default mode for providing semaphore locking of the buffer memory.
- *mutex=none* - Not used
- *mutex=no_interrupts* - not applicable on a Linux system
- *mutex=no_switching* - not applicable on a Linux system
- *mutex=mao split* - Splits the buffer in to half (or more) and allows one process to access part of the buffer whilst a second process is writing to another part.
- *TCP=(port number)* - Specifies which network port to use.
- *UDP=(port number)* - ditto
- *STCP=(port number)* - ditto
- *serialPortDevName=(serial port)* - Undocumented.
- *passwd=file_name.pwd* - Adds a layer of security to the buffer by requiring each process to provide a password.
- *bsem* - NIST documentation implies a key for a blocking semaphore, and if bsem=-1, blocking reads are prevented.
- *queue* - Enables queued message passing.
- *ascii* - Encode messages in a plain text format
- *disp* - Encode messages in a format suitable for display (???)
- *xdr* - Encode messages in External Data Representation. (see rpc/xdr.h for details).
- *diag* - Enables diagnostics stored in the buffer (timings and byte counts ?)

2.21.3 Process line

The original NIST format of the process line is:

P name buffer type host ops server timeout master c_num [type specific configs]

- *P* - identifies this line as a Process configuration.
- *name* - is the identifier of the process.
- *buffer* - is one of the buffers defined elsewhere in the config file.
- *type* - defines whether this process is local or remote relative to the buffer.

- *host* - specifies where on the network this process is running.
- *ops* - gives the process read only, write only, or read/write access to the buffer.
- *server* - specifies if this process will running a server for this buffer.
- *timeout* - sets the timeout characteristics for accesses to the buffer.
- *master* - indicates if this process is responsible for creating and destroying the buffer.
- *c_num* - an integer between zero and (max_procs -1)

2.21.4 Configuration Comments

Some of the configuration combinations are invalid, whilst others imply certain constraints. On a Linux system, GLOBMEM is obsolete, whilst PHANTOM is only really useful in the testing stage of an application, likewise for FILEMEM. LOCMEM is of little use for a multi-process application, and only offers limited performance advantages over SHMEM. This leaves SHMEM as the only buffer type to use with LinuxCNC.

The neut option is only of use in a multi-processor system where different (and incompatible) architectures are sharing a block of memory. The likelihood of seeing a system of this type outside of a museum or research establishment is remote and is only relevant to GLOBMEM buffers.

The RPC number is documented as being obsolete and is retained only for compatibility reasons.

With a unique buffer name, having a numerical identity seems to be pointless. Need to review the code to identify the logic. Likewise, the key field at first appears to be redundant, and it could be derived from the buffer name.

The purpose of limiting the number of processes allowed to connect to any one buffer is unclear from existing documentation and from the original source code. Allowing unspecified multiple processes to connect to a buffer is no more difficult to implement.

The mutex types boil down to one of two, the default “os_sem” or “mao split”. Most of the NML messages are relatively short and can be copied to or from the buffer with minimal delays, so split reads are not essential.

Data encoding is only relevant when transmitted to a remote process - Using TCP or UDP implies XDR encoding. Whilst ASCII encoding may have some use in diagnostics or for passing data to an embedded system that does not implement NML.

UDP protocols have fewer checks on data and allows a percentage of packets to be dropped. TCP is more reliable, but is marginally slower.

If LinuxCNC is to be connected to a network, one would hope that it is local and behind a firewall. About the only reason to allow access to LinuxCNC via the Internet would be for remote diagnostics - This can be achieved far more securely using other means, perhaps by a web interface.

The exact behavior when timeout is set to zero or a negative value is unclear from the NIST documents. Only INF and positive values are mentioned. However, buried in the source code of rcslib, it is apparent that the following applies:

timeout > 0 Blocking access until the timeout interval is reached or access to the buffer is available.

timeout = 0 Access to the buffer is only possible if no other process is reading or writing at the time.

timeout < 0 or INF Access is blocked until the buffer is available.

2.22 NML base class

Expand on the lists and the relationship between NML, NMLmsg, and the lower level cms classes.

Not to be confused with NMLmsg, RCS_STAT_MSG, or RCS_CMD_MSG.

NML is responsible for parsing the config file, configuring the cms buffers and is the mechanism for routing messages to the correct buffer(s). To do this, NML creates several lists for:

- cms buffers created or connected to.

- processes and the buffers they connect to
- a long list of format functions for each message type

This last item is probably the nub of much of the malignment of libnml/rcslib and NML in general. Each message that is passed via NML requires a certain amount of information to be attached in addition to the actual data. To do this, several formatting functions are called in sequence to assemble fragments of the overall message. The format functions will include NML_TYPE, MSG_TYPE, in addition to the data declared in derived NMLmsg classes. Changes to the order in which the formatting functions are called and also the variables passed will break compatibility with rcslib if messed with - There are reasons for maintaining rcslib compatibility, and good reasons for messing with the code. The question is, which set of reasons are overriding?

2.22.1 NML internals

2.22.1.1 NML constructor

NML::NML() parses the config file and stores it in a linked list to be passed to cms constructors in single lines. It is the function of the NML constructor to call the relevant cms constructor for each buffer and maintain a list of the cms objects and the processes associated with each buffer.

It is from the pointers stored in the lists that NML can interact with cms and why Doxygen fails to show the real relationships involved.

Note
The config is stored in memory before passing a pointer to a specific line to the cms constructor. The cms constructor then parses the line again to extract a couple of variables... It would make more sense to do ALL the parsing and save the variables in a struct that is passed to the cms constructor - This would eliminate string handling and reduce duplicate code in cms....

2.22.1.2 NML read/write

Calls to NML::read and NML::write both perform similar tasks in so much as processing the message - The only real variation is in the direction of data flow.

A call to the read function first gets data from the buffer, then calls format_output(), whilst a write function would call format_input() before passing the data to the buffer. It is in format_xxx() that the work of constructing or deconstructing the message takes place. A list of assorted functions are called in turn to place various parts of the NML header (not to be confused with the cms header) in the right order - The last function called is emcFormat() in emc.cc.

2.22.1.3 NMLmsg and NML relationships

NMLmsg is the base class from which all message classes are derived. Each message class must have a unique ID defined (and passed to the constructor) and also an update(*cms) function. The update() will be called by the NML read/write functions when the NML formatter is called - The pointer to the formatter will have been declared in the NML constructor at some point. By virtue of the linked lists NML creates, it is able to select cms pointer that is passed to the formatter and therefor which buffer is to be used.

2.23 Adding custom NML commands

LinuxCNC is pretty awesome, but some parts need some tweaking. As you know communication is done through NML channels, the data sent through such a channel is one of the classes defined in emc.hh (implemented in emc.cc). If somebody needs a message type that doesn't exist, he should follow these steps to add a new one. (The Message I added in the example is called EMC_IO_GENERIC (inherits EMC_IO_CMD_MSG (inherits RCS_CMD_MSG)))

1. add the definition of the EMC_IO_GENERIC class to emc2/src/emc/nml_intf/emc.hh

2. add the type define: #define EMC_IO_GENERIC_TYPE ((NMLTYPE) 1605)

    a. (I chose 1605, because it was available) to emc2/src/emc/nml_intf/emc.hh

3. add case EMC_IO_GENERIC_TYPE to emcFormat in emc2/src/emc/nml_intf/emc.cc
4. add case EMC_IO_GENERIC_TYPE to emc_symbol_lookup in emc2/src/emc/nml_intf/emc.cc
5. add EMC_IO_GENERIC::update function to emc2/src/emc/nml_intf/emc.cc

Recompile, and the new message should be there. The next part is to send such messages from somewhere, and receive them in another place, and do some stuff with it.

2.24 The Tool Table and Toolchanger

LinuxCNC interfaces with toolchanger hardware, and has an internal toolchanger abstraction. LinuxCNC manages tool information in a tool table file.

2.24.1 Toolchanger abstraction in LinuxCNC

LinuxCNC supports two kinds of toolchanger hardware, called *nonrandom* and *random*. The ini setting [EMCIO]RANDOM_TOOLCHA controls which of these kinds of hardware LinuxCNC thinks it's connected to.

2.24.1.1 Nonrandom Toolchangers

Nonrandom toolchanger hardware puts each tool back in the pocket it was originally loaded from.

Examples of nonrandom toolchanger hardware are the "manual" toolchanger, lathe tool turrents, and rack toolchangers.

When configured for a nonrandom toolchanger, LinuxCNC does not change the pocket number in the tool table file as tools are loaded and unloaded. Internal to LinuxCNC, on tool change the tool information is **copied** from the tool table's source pocket to pocket 0 (which represents the spindle), replacing whatever tool information was previously there.

Note
In LinuxCNC configured for nonrandom toolchanger, tool 0 (T0) has special meaning: "no tool". T0 may not appear in the tool table file, and changing to T0 will result in LinuxCNC thinking it's got an empty spindle.

2.24.1.2 Random Toolchangers

Random toolchanger hardware swaps the tool in the spindle (if any) with the requested tool on tool change. Thus the pocket that a tool resides in changes as it is swapped in and out of the spindle.

An example of random toolchanger hardware is a carousel toolchanger.

When configured for a random toolchanger, LinuxCNC swaps the pocket number of the old and the new tool in the tool table file when tools are loaded. Internal to LinuxCNC, on tool change, the tool information is **swapped** between the tool table's source pocket and pocket 0 (which represents the spindle). So after a tool change, pocket 0 in the tool table has the tool information for the new tool, and the pocket that the new tool came from has the tool information for the old tool (the tool that was in the spindle before the tool change), if any.

Note
In LinuxCNC configured for random toolchanger, tool 0 (T0) has **no** special meaning. It is treated exactly like any other tool in the tool table. It is customary to use T0 to represent "no tool" (ie, a tool with zero TLO), so that the spindle can be conveniently emptied when needed.

2.24.2 The Tool Table

LinuxCNC keeps track of tools in a file called the tool table. The tool table records the following information for each tool:

tool number
An integer that uniquely identifies this tool. Tool numbers are handled differently by LinuxCNC when configured for random and nonrandom toolchangers:

- When LinuxCNC is configured for a nonrandom toolchanger this number must be positive. T0 gets special handling and is not allowed to appear in the tool table.
- When LinuxCNC is configured for a random toolchanger this number must be non-negative. T0 is allowed in the tool table, and is usually used to represent "no tool", ie the empty pocket.

pocket number
An integer that identifies the pocket or slot in the toolchanger hardware where the tool resides. Pocket numbers are handled differently by LinuxCNC when configured for random and nonrandom toolchangers:

- When LinuxCNC is configured for a nonrandom toolchanger, the pocket number in the tool file can be any positive integer (pocket 0 is not allowed). LinuxCNC silently compactifies the pocket numbers when it loads the tool file, so there may be a difference between the pocket numbers in the tool file and the internal pocket numbers used by LinuxCNC-with-nonrandom-toolchanger.
- When LinuxCNC is configured for a random toolchanger, the pocket numbers in the tool file must be between 0 and 1000, inclusive. Pockets 1-1000 are in the toolchanger, pocket 0 is the spindle.

diameter
Diameter of the tool, in machine units.

tool length offset
Tool length offset (also called TLO), in up to 9 axes, in machine units. Axes that don't have a specified TLO get 0.

2.24.3 Gcodes affecting tools

The gcodes that use or affect tool information are:

2.24.3.1 Txxx

Tells the toolchanger hardware to prepare to switch to a specified tool `xxx`.

Handled by `Interp::convert_tool_select()`.

1. The machine is asked to prepare to switch to the selected tool by calling the Canon function `SELECT_POCKET()` with the pocket number of the requested tool.
   a. (saicanon) No-op.
   b. (emccanon) Builds an `EMC_TOOL_PREPARE` message with the requested pocket number and sends it to Task, which sends it on to IO. IO gets the message and asks HAL to prepare the pocket by setting `iocontrol.0.tool-prep-pocket`, `iocontrol.0.tool-prep-number`, and `iocontrol.0.tool-prepare`. IO then repeatedly calls `read_tool_inputs()` to poll the HAL pin `iocontrol.0.tool-prepared`, which signals from the toolchanger hardware, via HAL, to IO that the requested tool prep is complete. When that pin goes True, IO sets `emcioStatus.tool.pocketPrepped` to the requested tool's pocket number.
2. Back in interp, `settings->selected_pocket` is assigned the pocket number of the requested tool *xxx*.

2.24.3.2 M6

Tells the toolchanger to switch to the currently selected tool (selected by the previous Txxx command).

Handled by `Interp::convert_tool_change()`.

1. The machine is asked to change to the selected tool by calling the Canon function `CHANGE_TOOL()` with `settings->selected_pocket`.
   a. (saicanon) Sets sai's `_active_slot` to the passed-in pocket number. Tool information is copied from the selected pocket of of the tool table (ie, from sai's `_tools[_active_slot]`) to the spindle (aka sai's `_tools[0]`).
   b. (emccanon) Sends an `EMC_TOOL_LOAD` message to Task, which sends it to IO. IO sets `emcioStatus.tool.toolInSpindle` to the tool number of the tool in the pocket identified by `emcioStatus.tool.pocketPrepped` (set by `Txxx` aka `SELECT_POCKET()`). It then requests that the toolchanger hardware perform a tool change, by setting the HAL pin `iocontrol.0.tool-change` to True. Later, IO's `read_tool_inputs()` will sense that the HAL pin `iocontrol.0.tool_changed` has been set to True, indicating the toolchanger has completed the tool change. When this happens, it calls `load_tool()` to update the machine state.
      i. `load_tool()` with a nonrandom toolchanger config copies the tool information from the selected pocket to the spindle (pocket 0).
      ii. `load_tool()` with a random toolchanger config swaps tool information between pocket 0 (the spindle) and the selected pocket, then saves the tool table.
2. Back in interp, `settings->current_pocket` is assigned the new tool from `settings->selected_pocket` (set by `Txxx`). The relevant numbered parameters (#5400-#5413) are updated with the new tool information from pocket 0 (spindle).

2.24.3.3 G43/G43.1/G49

Apply tool length offset. G43 uses the TLO of the currently loaded tool, or of a specified tool if the H-word is given in the block. G43.1 gets TLO from axis-words in the block. G49 cancels the TLO (it uses 0 for the offset for all axes).

Handled by `Interp::convert_tool_length_offset()`.

1. It starts by building an `EmcPose` containing the 9-axis offsets to use. For `G43.1`, these tool offsets come from axis words in the current block. For `G43` these offsets come from the current tool (the tool in pocket 0), or from the tool specified by the H-word in the block. For G49, the offsets are all 0.
2. The offsets are passed to Canon's `USE_TOOL_LENGTH_OFFSET()` function.
   a. (saicanon) Records the TLO in `_tool_offset`.
   b. (emccanon) Builds an `EMC_TRAJ_SET_OFFSET` message containing the offsets and sends it to Task. Task copies the offsets to `emcStatus->task.toolOffset` and sends them on to Motion via an `EMCMOT_SET_OFFSET` command. Motion copies the offsets to `emcmotStatus->tool_offset`, where it gets used to offset future motions.
3. Back in interp, the offsets are recorded in `settings->tool_offset`. The effective pocket is recorded in `settings->tool_offset_index`, though this value is never used.

2.24.3.4 G10 L1/L10/L11

Modifies the tool table.

Handled by `Interp::convert_setup_tool()`.

1. Picks the tool number out of the P-word in the block and finds the pocket for that tool:

a. With a nonrandom toolchanger config this is always the pocket number in the toolchanger (even when the tool is in the spindle).
b. With a random toolchanger config, if the tool is currently loaded it uses pocket 0 (pocket 0 means "the spindle"), and if the tool is not loaded it uses the pocket number in the tool changer. (This difference is important.)

2. Figures out what the new offsets should be.
3. The new tool information (diameter, offsets, angles, and orientation), along with the tool number and pocket number, are passed to the Canon call SET_TOOL_TABLE_ENTRY().

a. (saicanon) Copy the new tool information to the specified pocket (in sai's internal tool table, `_tools`).
b. (emccanon) Build an `EMC_TOOL_SET_OFFSET` message with the new tool information, and send it to Task, which passes it to IO. IO updates the specified pocket in its internal copy of the tool table (`emcioStatus.tool.toolTable`), and if the specified tool is currently loaded (it is compared to `emcioStatus.tool.toolInSpindle`) then the new tool information is copied to pocket 0 (the spindle) as well. (FIXME: that's a buglet, should only be copied on nonrandom machines.) Finally IO saves the new tool table.

4. Back in interp, if the modified tool is currently loaded in the spindle, and if the machine is a non-random toolchanger, then the new tool information is copied from the tool's home pocket to pocket 0 (the spindle) in interp's copy of the tool table, `settings->tool_table`. (This copy is not needed on random tool changer machines because there, tools don't have a home pocket and instead we just updated the tool in pocket 0 directly.)
5. The relevant numbered parameters (#5400-#5413) are updated from the tool information in the spindle (by copying the information from interp's `settings->tool_table` to `settings->parameters`). (FIXME: this is a buglet, the params should only be updated if it was the current tool that was modified).
6. If the modified tool is currently loaded in the spindle, and if the config is for a nonrandom toolchanger, then the new tool information is written to the tool table's pocket 0 as well, via a second call to SET_TOOL_TABLE_ENTRY(). (This second tool-table update is not needed on random toolchanger machines because there, tools don't have a home pocket and instead we just updated the tool in pocket 0 directly.)

2.24.3.5 M61

Set current tool number. This switches LinuxCNC's internal representation of which tool is in the spindle, without actually moving the toolchanger or swapping any tools.

Handled by `Interp::convert_tool_change()`.

Canon: `CHANGE_TOOL_NUMBER()`

settings->current_pocket is assigned the pocket number currently holding the tool specified by the Q-word argument.

2.24.3.6 G41/G41.1/G42/G42.1

Enable cutter radius compensation (usually called *cutter comp*).

Handled by `Interp::convert_cutter_compensation_on()`.

No Canon call, cutter comp happens in the interpreter. Uses the tool table in the expected way: if a D-word tool number is supplied it looks up the pocket number of the specified tool number in the table, and if no D-word is supplied it uses pocket 0 (the spindle).

2.24.3.7 G40

Cancel cutter radius compensation.

Handled by `Interp::convert_cutter_compensation_off()`.

No Canon call, cutter comp happens in the interpreter. Does not use the tool table.

2.24.4 Internal state variables

This is not an exhaustive list! Tool information is spread through out LinuxCNC.

2.24.4.1 IO

`emcioStatus` is of type `EMC_IO_STAT`

emcioStatus.tool.pocketPrepped
When IO gets the signal from HAL that the toolchanger prep is complete (after a `Txxx` command), this variable is set to the pocket of the requested tool. When IO gets the signal from HAL that the tool change itself is complete (after an `M6` command), this variable gets reset to -1.

emcioStatus.tool.toolInSpindle
Tool number of the tool currently installed in the spindle. Exported on the HAL pin `iocontrol.0.tool-number` (s32).

emcioStatus.tool.toolTable[]
An array of `CANON_TOOL_TABLE` structures, `CANON_POCKETS_MAX` long. Loaded from the tool table file at startup and maintained there after. Index 0 is the spindle, indexes 1-(CANON_POCKETS_MAX-1) are the pockets in the toolchanger. This is a complete copy of the tool information, maintained separately from Interp's `settings.tool_table`.

2.24.4.2 interp

`settings` is of type `settings`, which is `struct setup_struct`. Defined in `src/emc/rs274ngc/interp_internal.hh`.

settings.selected_pocket
Pocket of the tool most recently selected by `Txxx`.

settings.current_pocket
Original pocket of the tool currently in the spindle. In other words: which toolchanger pocket the tool that's currently in the spindle was loaded from.

settings.tool_table[]
An array of tool information. The index into the array is the "pocket number" (aka "slot number"). Pocket 0 is the spindle, pockets 1 through (CANON_POCKETS_MAX-1) are the pockets of the toolchanger.

settings.tool_offset_index
Unused. FIXME: Should probably be removed.

settings.toolchange_flag
Interp sets this to true when calling Canon's CHANGE_TOOL() function. It is checked in `Interp::convert_tool_length_offset()` to decide which pocket to use for G43 (with no H-word): `settings->current_pocket` if the tool change is still in progress, pocket 0 (the spindle) if the tool change is complete.

settings.random_toolchanger
Set from the ini variable `[EMCIO]RANDOM_TOOLCHANGER` at startup. Controls various tool table handling logic. (IO also reads this ini variable and changes its behavior based on it. For example, when saving the tool table, random toolchanger save the tool in the spindle (pocket 0), but non-random toolchanger save each tool in its "home pocket".)

settings.tool_offset
This is an `EmcPose` variable.

- Used to compute position in various places.
- Sent to Motion via the `EMCMOT_SET_OFFSET` message. All motion does with the offsets is export them to the HAL pins `motion.0.tooloffset.[xyzabcuvw]`. FIXME: export these from someplace closer to the tool table (io or interp, probably) and remove the EMCMOT_SET_OFFSET message.

settings.pockets_max
Used interchangably with `CANON_POCKETS_MAX` (a #defined constant, set to 1000 as of April 2020). FIXME: This settings variable is not currently useful and should probably be removed.

settings.tool_table
This is an array of `CANON_TOOL_TABLE` structures (defined in `src/emc/nml_intf/emctool.h`), with `CANON_POCKETS_MAX` entries. Indexed by "pocket number", aka "slot number". Index 0 is the spindle, indexes 1-(CANON_POCKETS_MA 1) are the pockets in the tool changer. On a random toolchanger pocket numbers are meaningful. On a nonrandom toolchanger pockets are meaningless; the pocket numbers in the tool table file are ignored and tools are assigned to `tool_table` slots sequentially.

settings.tool_change_at_g30 , settings.tool_change_quill_up , settings.tool_change_with_spindle_on
These are set from ini variables in the `[EMCIO]` section, and control how tool changes are performed.

2.25 Reckoning of joints and axes

2.25.1 In the status buffer

The status buffer is used by Task and the UIs.

FIXME: `axis_mask` and `axes` overspecify the number of axes

`status.motion.traj.axis_mask`
A bitmask with a "1" for the axes that are present and a "0" for the axes that are not present. X is bit 0, Y is bit 1, etc. For example, a machine with X and Z axes would have an `axis_mask` of 0x5, an XYZ machine would have 0x7, and an XYZB machine would have an `axis_mask` of 0x17.

`status.motion.traj.axes` (deprecated)
The value of this variable is one more than the index of the highest-numbered axis present on the machine. As in the `axis_mask`, the index of X in 0, Y is 1, etc. An XZ machine has `axes` value of 3, as does an XYZ machine. An XYZW machine has `axes` value 9. This variable is not terribly helpful, and its use is deprecated. Use `axis_mask` instead.

`status.motion.traj.joints`
A count of the number of joints the machine has. A normal lathe has 2 joints; one driving the X axis and one driving the Z axis. An XYYZ gantry mill has 4 joints; one driving X, one driving one side of the Y, one driving the other side of the Y, and one driving Z. An XYZA mill also has 4 joints.

`status.motion.axis[EMCMOT_MAX_AXIS]`
An array of `EMCMOT_MAX_AXIS` axis structures. `axis[n]` is valid if `(axis_mask & (1 << n))` is True. If `(axis_mask & (1 << n))` is False, then `axis[n]` does not exist on this machine and must be ignored.

`status.motion.joint[EMCMOT_MAX_JOINTS]`
An array of `EMCMOT_MAX_JOINTS` joint structures. `joint[0]` through `joint[joints-1]` are valid, the others do not exist on this machine and must be ignored.

Things are not this way currently in the joints-axes branch, but deviations from this design are considered bugs. For an example of such a bug, see the treatment of axes in src/emc/ini/initraj.cc:loadTraj(). There are undoubtedly more, and I need your help to find them and fix them.

2.25.2 In Motion

The Motion controller realtime component first gets the number of joints from the `num_joints` load-time parameter. This determines how many joints worth of HAL pins are created at startup.

Motion's number of joints can be changed at runtime using the `EMCMOT_SET_NUM_JOINTS` command from Task.

The Motion controller always operates on `EMCMOT_MAX_AXIS` axes. It always creates nine sets of `axis.*.*` pins.

Chapter 3

NML Messages

for details see src/emc/nml_intf/emc.hh

OPERATOR

```
    EMC_OPERATOR_ERROR_TYPE
    EMC_OPERATOR_TEXT_TYPE
    EMC_OPERATOR_DISPLAY_TYPE
```

JOINT

```
    EMC_JOINT_SET_JOINT_TYPE
    EMC_JOINT_SET_UNITS_TYPE
    EMC_JOINT_SET_MIN_POSITION_LIMIT_TYPE
    EMC_JOINT_SET_MAX_POSITION_LIMIT_TYPE
    EMC_JOINT_SET_FERROR_TYPE
    EMC_JOINT_SET_HOMING_PARAMS_TYPE
    EMC_JOINT_SET_MIN_FERROR_TYPE
    EMC_JOINT_SET_MAX_VELOCITY_TYPE
    EMC_JOINT_INIT_TYPE
    EMC_JOINT_HALT_TYPE
    EMC_JOINT_ABORT_TYPE
    EMC_JOINT_ENABLE_TYPE
    EMC_JOINT_DISABLE_TYPE
    EMC_JOINT_HOME_TYPE
    EMC_JOINT_ACTIVATE_TYPE
    EMC_JOINT_DEACTIVATE_TYPE
    EMC_JOINT_OVERRIDE_LIMITS_TYPE
    EMC_JOINT_LOAD_COMP_TYPE
    EMC_JOINT_SET_BACKLASH_TYPE
    EMC_JOINT_UNHOME_TYPE
    EMC_JOINT_STAT_TYPE
```

AXIS

```
    EMC_AXIS_STAT_TYPE
```

JOG

```
    EMC_JOG_CONT_TYPE
    EMC_JOG_INCR_TYPE
    EMC_JOG_ABS_TYPE
    EMC_JOG_STOP_TYPE
```

TRAJ

```
    EMC_TRAJ_SET_AXES_TYPE
    EMC_TRAJ_SET_UNITS_TYPE
    EMC_TRAJ_SET_CYCLE_TIME_TYPE
    EMC_TRAJ_SET_MODE_TYPE
    EMC_TRAJ_SET_VELOCITY_TYPE
    EMC_TRAJ_SET_ACCELERATION_TYPE
    EMC_TRAJ_SET_MAX_VELOCITY_TYPE
    EMC_TRAJ_SET_MAX_ACCELERATION_TYPE
    EMC_TRAJ_SET_SCALE_TYPE
    EMC_TRAJ_SET_RAPID_SCALE_TYPE
    EMC_TRAJ_SET_MOTION_ID_TYPE
    EMC_TRAJ_INIT_TYPE
    EMC_TRAJ_HALT_TYPE
    EMC_TRAJ_ENABLE_TYPE
    EMC_TRAJ_DISABLE_TYPE
    EMC_TRAJ_ABORT_TYPE
    EMC_TRAJ_PAUSE_TYPE
    EMC_TRAJ_STEP_TYPE
    EMC_TRAJ_RESUME_TYPE
    EMC_TRAJ_DELAY_TYPE
    EMC_TRAJ_LINEAR_MOVE_TYPE
    EMC_TRAJ_CIRCULAR_MOVE_TYPE
    EMC_TRAJ_SET_TERM_COND_TYPE
    EMC_TRAJ_SET_OFFSET_TYPE
    EMC_TRAJ_SET_G5X_TYPE
    EMC_TRAJ_SET_HOME_TYPE
    EMC_TRAJ_SET_ROTATION_TYPE
    EMC_TRAJ_SET_G92_TYPE
    EMC_TRAJ_CLEAR_PROBE_TRIPPED_FLAG_TYPE
    EMC_TRAJ_PROBE_TYPE
    EMC_TRAJ_SET_TELEOP_ENABLE_TYPE
    EMC_TRAJ_SET_SPINDLESYNC_TYPE
    EMC_TRAJ_SET_SPINDLE_SCALE_TYPE
    EMC_TRAJ_SET_FO_ENABLE_TYPE
    EMC_TRAJ_SET_SO_ENABLE_TYPE
    EMC_TRAJ_SET_FH_ENABLE_TYPE
    EMC_TRAJ_RIGID_TAP_TYPE
    EMC_TRAJ_STAT_TYPE
```

MOTION

```
    EMC_MOTION_INIT_TYPE
    EMC_MOTION_HALT_TYPE
    EMC_MOTION_ABORT_TYPE
    EMC_MOTION_SET_AOUT_TYPE
    EMC_MOTION_SET_DOUT_TYPE
    EMC_MOTION_ADAPTIVE_TYPE
    EMC_MOTION_STAT_TYPE
```

TASK

```
    EMC_TASK_INIT_TYPE
    EMC_TASK_HALT_TYPE
    EMC_TASK_ABORT_TYPE
    EMC_TASK_SET_MODE_TYPE
    EMC_TASK_SET_STATE_TYPE
    EMC_TASK_PLAN_OPEN_TYPE
```

```
    EMC_TASK_PLAN_RUN_TYPE
    EMC_TASK_PLAN_READ_TYPE
    EMC_TASK_PLAN_EXECUTE_TYPE
    EMC_TASK_PLAN_PAUSE_TYPE
    EMC_TASK_PLAN_STEP_TYPE
    EMC_TASK_PLAN_RESUME_TYPE
    EMC_TASK_PLAN_END_TYPE
    EMC_TASK_PLAN_CLOSE_TYPE
    EMC_TASK_PLAN_INIT_TYPE
    EMC_TASK_PLAN_SYNCH_TYPE
    EMC_TASK_PLAN_SET_OPTIONAL_STOP_TYPE
    EMC_TASK_PLAN_SET_BLOCK_DELETE_TYPE
    EMC_TASK_PLAN_OPTIONAL_STOP_TYPE
    EMC_TASK_STAT_TYPE
```

TOOL

```
    EMC_TOOL_INIT_TYPE
    EMC_TOOL_HALT_TYPE
    EMC_TOOL_ABORT_TYPE
    EMC_TOOL_PREPARE_TYPE
    EMC_TOOL_LOAD_TYPE
    EMC_TOOL_UNLOAD_TYPE
    EMC_TOOL_LOAD_TOOL_TABLE_TYPE
    EMC_TOOL_SET_OFFSET_TYPE
    EMC_TOOL_SET_NUMBER_TYPE
    EMC_TOOL_START_CHANGE_TYPE
    EMC_TOOL_STAT_TYPE
```

AUX

```
    EMC_AUX_ESTOP_ON_TYPE
    EMC_AUX_ESTOP_OFF_TYPE
    EMC_AUX_ESTOP_RESET_TYPE
    EMC_AUX_INPUT_WAIT_TYPE
    EMC_AUX_STAT_TYPE
```

SPINDLE

```
    EMC_SPINDLE_ON_TYPE
    EMC_SPINDLE_OFF_TYPE
    EMC_SPINDLE_INCREASE_TYPE
    EMC_SPINDLE_DECREASE_TYPE
    EMC_SPINDLE_CONSTANT_TYPE
    EMC_SPINDLE_BRAKE_RELEASE_TYPE
    EMC_SPINDLE_BRAKE_ENGAGE_TYPE
    EMC_SPINDLE_SPEED_TYPE
    EMC_SPINDLE_ORIENT_TYPE
    EMC_SPINDLE_WAIT_ORIENT_COMPLETE_TYPE
    EMC_SPINDLE_STAT_TYPE
```

COOLANT

```
    EMC_COOLANT_MIST_ON_TYPE
    EMC_COOLANT_MIST_OFF_TYPE
    EMC_COOLANT_FLOOD_ON_TYPE
    EMC_COOLANT_FLOOD_OFF_TYPE
    EMC_COOLANT_STAT_TYPE
```

LUBE

```
    EMC_LUBE_ON_TYPE
    EMC_LUBE_OFF_TYPE
    EMC_LUBE_STAT_TYPE
```

IO (INPUT/OUTPUT)

```
    EMC_IO_INIT_TYPE
    EMC_IO_HALT_TYPE
    EMC_IO_ABORT_TYPE
    EMC_IO_SET_CYCLE_TIME_TYPE
    EMC_IO_STAT_TYPE
    EMC_IO_PLUGIN_CALL_TYPE
```

OTHER

```
    EMC_NULL_TYPE
    EMC_SET_DEBUG_TYPE
    EMC_SYSTEM_CMD_TYPE
    EMC_INIT_TYPE
    EMC_HALT_TYPE
    EMC_ABORT_TYPE
    EMC_STAT_TYPE
    EMC_EXEC_PLUGIN_CALL_TYPE
```

Chapter 4

Coding Style

This chapter describes the source code style preferred by the LinuxCNC team.

4.1 Do no harm

When making small edits to code in a style different than the one described below, observe the local coding style. Rapid changes from one coding style to another decrease code readability.

Never check in code after running “indent” on it. The whitespace changes introduced by indent make it more difficult to follow the revision history of the file.

Do not use an editor that makes unneeded changes to whitespace (e.g., which replaces 8 spaces with a tabstop on a line not otherwise modified, or word-wraps lines not otherwise modified)

4.2 Tab Stops

A tab stop always corresponds to 8 spaces. Do not write code that displays correctly only with a differing tab stop setting.

4.3 Indentation

Use 4 spaces per level of indentation. Combining 8 spaces into one tab is acceptable but not required.

4.4 Placing Braces

Put the opening brace last on the line, and put the closing brace first:

```
if (x) {
    // do something appropriate
}
```

The closing brace is on a line of its own, except in the cases where it is followed by a continuation of the same statement, i.e. a *while* in a do-statement or an *else* in an if-statement, like this:

```
do {
    // something important
} while (x > 0);
```

and

```
if (x == y) {
    // do one thing
} else if (x < y) {
    // do another thing
} else {
    // do a third thing
}
```

This brace-placement also minimizes the number of empty (or almost empty) lines, which allows a greater amount of code or comments to be visible at once in a terminal of a fixed size.

4.5 Naming

C is a Spartan language, and so should your naming be. Unlike Modula-2 and Pascal programmers, C programmers do not use cute names like ThisVariableIsATemporaryCounter. A C programmer would call that variable *tmp*, which is much easier to write, and not the least more difficult to understand.

However, descriptive names for global variables are a must. To call a global function *foo* is a shooting offense.

GLOBAL variables (to be used only if you **really** need them) need to have descriptive names, as do global functions. If you have a function that counts the number of active users, you should call that *count_active_users()* or similar, you should **not** call it *cntusr()*.

Encoding the type of a function into the name (so-called Hungarian notation) is brain damaged - the compiler knows the types anyway and can check those, and it only confuses the programmer. No wonder Microsoft makes buggy programs.

LOCAL variable names should be short, and to the point. If you have some random integer loop counter, it should probably be called *i*. Calling it *loop_counter* is non-productive, if there is no chance of it being misunderstood. Similarly, *tmp* can be just about any type of variable that is used to hold a temporary value.

If you are afraid to mix up your local variable names, you have another problem, which is called the function-growth-hormone-imbalance syndrome. See next chapter.

4.6 Functions

Functions should be short and sweet, and do just one thing. They should fit on one or two screenfuls of text (the ISO/ANSI screen size is 80x24, as we all know), and do one thing and do that well.

The maximum length of a function is inversely proportional to the complexity and indentation level of that function. So, if you have a conceptually simple function that is just one long (but simple) case-statement, where you have to do lots of small things for a lot of different cases, it's OK to have a longer function.

However, if you have a complex function, and you suspect that a less-than-gifted first-year high-school student might not even understand what the function is all about, you should adhere to the maximum limits all the more closely. Use helper functions with descriptive names (you can ask the compiler to in-line them if you think it's performance-critical, and it will probably do a better job of it that you would have done).

Another measure of the function is the number of local variables. They shouldn't exceed 5-10, or you're doing something wrong. Re-think the function, and split it into smaller pieces. A human brain can generally easily keep track of about 7 different things, anything more and it gets confused. You know you're brilliant, but maybe you'd like to understand what you did 2 weeks from now.

4.7 Commenting

Comments are good, but there is also a danger of over-commenting. NEVER try to explain HOW your code works in a comment: it's much better to write the code so that the **working** is obvious, and it's a waste of time to explain badly written code.

Generally, you want your comments to tell WHAT your code does, not HOW. A boxed comment describing the function, return value, and who calls it placed above the body is good. Also, try to avoid putting comments inside a function body: if the function is so complex that you need to separately comment parts of it, you should probably re-read the Functions section again. You can make small comments to note or warn about something particularly clever (or ugly), but try to avoid excess. Instead, put the comments at the head of the function, telling people what it does, and possibly WHY it does it.

If comments along the lines of /* Fix me */ are used, please, please, say why something needs fixing. When a change has been made to the affected portion of code, either remove the comment, or amend it to indicate a change has been made and needs testing.

4.8 Shell Scripts & Makefiles

Not everyone has the same tools and packages installed. Some people use vi, others emacs - A few even avoid having either package installed, preferring a lightweight text editor such as nano or the one built in to Midnight Commander.

gawk versus mawk - Again, not everyone will have gawk installed, mawk is nearly a tenth of the size and yet conforms to the Posix AWK standard. If some obscure gawk specific command is needed that mawk does not provide, than the script will break for some users. The same would apply to mawk. In short, use the generic awk invocation in preference to gawk or mawk.

4.9 C++ Conventions

C++ coding styles are always likely to end up in heated debates (a bit like the emacs versus vi arguments). One thing is certain however, a common style used by everyone working on a project leads to uniform and readable code.

Naming conventions: Constants either from #defines or enumerations should be in upper case through out. Rationale: Makes it easier to spot compile time constants in the source code. e.g. EMC_MESSAGE_TYPE

Classes and Namespaces should capitalize the first letter of each word and avoid underscores. Rationale: Identifies classes, constructors and destructors. e.g. GtkWidget

Methods (or function names) should follow the C recommendations above and should not include the class name. Rationale: Maintains a common style across C and C++ sources. e.g. get_foo_bar()

However, boolean methods are easier to read if they avoid underscores and use an *is* prefix (not to be confused with methods that manipulate a boolean). Rationale: Identifies the return value as TRUE or FALSE and nothing else. e.g. isOpen, isHomed

Do NOT use *Not* in a boolean name, it leads only leads to confusion when doing logical tests. e.g. isNotOnLimit or is_not_on_limit are BAD.

Variable names should avoid the use of upper case and underscores except for local or private names. The use of global variables should be avoided as much as possible. Rationale: Clarifies which are variables and which are methods. Public: e.g. axislimit Private: e.g. maxvelocity_

Specific method naming conventions

The terms get and set should be used where an attribute is accessed directly. Rationale: Indicates the purpose of the function or method. e.g. get_foo set_bar

For methods involving boolean attributes, set & reset is preferred. Rationale: As above. e.g. set_amp_enable reset_amp_fault

Math intensive methods should use compute as a prefix. Rationale: Shows that it is computationally intensive and will hog the CPU. e.g. compute_PID

Abbreviations in names should be avoided where possible - The exception is for local variable names. Rationale: Clarity of code. e.g. pointer is preferred over ptr compute is preferred over cmp compare is again preferred over cmp.

Enumerates and other constants can be prefixed by a common type name e.g. enum COLOR { COLOR_RED, COLOR_BLUE };

Excessive use of macros and defines should be avoided - Using simple methods or functions is preferred. Rationale: Improves the debugging process.

Include Statements Header files must be included at the top of a source file and not scattered throughout the body. They should be sorted and grouped by their hierarchical position within the system with the low level files included first. Include file paths should NEVER be absolute - Use the compiler -I flag instead. Rationale: Headers may not be in the same place on all systems.

Pointers and references should have their reference symbol next to the variable name rather than the type name. Rationale: Reduces confusion. e.g. float *x or int &i

Implicit tests for zero should not be used except for boolean variables. e.g. if (spindle_speed != 0) NOT if (spindle_speed)

Only loop control statements must be included in a for() construct. e.g. sum = 0; for (i = 0; i < 10; i++) { sum += value[i]; }

NOT for (i = 0, sum =0; i < 10; i++) sum += value[i];

Likewise, executable statements in conditionals must be avoided. e.g. if (fd = open(file_name) is bad.

Complex conditional statements should be avoided - Introduce temporary boolean variables instead.

Parentheses should be used in plenty in mathematical expressions - Do not rely on operator precedence when an extra parentheses would clarify things.

File names: C++ sources and headers use .cc and .hh extension. The use of .c and .h are reserved for plain C. Headers are for class, method, and structure declarations, not code (unless the functions are declared inline).

4.10 Python coding standards

Use the PEP 8 style for Python code.

4.11 Comp coding standards

In the declaration portion of a .comp file, begin each declaration at the first column. Insert extra blank lines when they help group related items.

In the code portion of a .comp file, follow normal C coding style.

Chapter 5

Building LinuxCNC

5.1 Introduction

This document describes how to build the LinuxCNC software and documentation from source. This is primarily useful if you are a developer who is modifying LinuxCNC. It can also be useful if you're a user who is testing developer branches, though then you also have the option of just installing Debian packages from the buildbot: http://buildbot.linuxcnc.org

5.1.1 Quick Start

For the impatient, try this:

```
> git clone git://github.com/linuxcnc/linuxcnc.git linuxcnc-dev
> cd linuxcnc-dev/src
> ./autogen.sh
> ./configure --with-realtime=uspace
> make
```

That will probably fail! That doesn't make you a bad person, it just means you should read this whole document to find out how to fix your problems. Especially the section on Satisfying Build Dependencies.

If you are running on a realtime-capable system (such as an install from the LinuxCNC Live/Install Image, see the Realtime section below), one extra build step is needed at this time:

```
> sudo make setuid
```

After you've successfully built LinuxCNC it's time to run the tests:

```
> source ../scripts/rip-environment
> runtests
```

This might fail too! Read this whole document, but especially the section on Setting up the test environment.

5.2 Supported Platforms

The LinuxCNC project targets modern Debian-based distributions, including Debian, Ubuntu, and Mint.

We continuously test on the platforms listed at http://buildbot.linuxcnc.org.

LinuxCNC builds on most other Linux distributions, though dependency management will be more manual and less automatic. Patches to improve portability to new platforms are always welcome.

5.2.1 Realtime

LinuxCNC is a machine tool controller, and it requires a realtime platform to do this job. This version of LinuxCNC supports three realtime platforms

RTAI
From https://www.rtai.org. A Linux kernel with the RTAI patch is available from the Debian archive at http://www.linuxcnc.org. See Getting LinuxCNC for installation instructions.

Xenomai
From https://xenomai.org. You will have to compile or obtain a Xenomai kernel yourself.

Preempt-RT
From https://rt.wiki.kernel.org. A Linux kernel with the Preempt-RT patch is occasionally available from the Debian archive at https://www.debian.org, and from the wayback machine at https://snapshot.debian.org.

To make use of the realtime capabilities of LinuxCNC, certain parts of LinuxCNC need to run with root priviledges. To enable root for these parts, run this extra command after the `make` that builds LinuxCNC:

```
> sudo make setuid
```

5.2.2 Non-realtime

LinuxCNC can also be built and run on non-realtime platforms, such as a regular install of Debian or Ubuntu without any special realtime kernel.

In this mode LinuxCNC is not useful for controlling machine tools, but it is useful for simulating the execution of G-code and for testing the non-realtime parts of the system (such as the user interfaces, and some kinds of components and device drivers).

5.3 Build modes

There are two ways to build LinuxCNC: the developer-friendly "run in place" mode and the user-friendly Debian packaging mode.

5.3.1 Building for Run In Place

In a Run-In-Place build, the LinuxCNC programs are compiled from source and then run directly from within the build directory. Nothing is installed outside the build directory.

This is quick and easy, and suitable for rapid iteration of changes.

The LinuxCNC test suite runs only in a Run-In-Place build.

Most LinuxCNC developers primarily build using this mode.

Building for Run-In-Place follows the steps in the Quick Start section at the top of this document, possibly with different arguments to `src/configure` and `make`.

5.3.1.1 `src/configure` arguments

The `src/configure` script configures how the source code will be compiled. It takes many optional arguments.

List all arguments to `src/configure` by running this:

```
> cd linuxcnc-dev/src
> ./configure --help
```

The most commonly used arguments are:

--with-realtime=uspace
: Build for any realtime platform, or for non-realtime. The resulting LinuxCNC executables will run on both a Linux kernel with Preempt-RT patches (providing realtime machine control) and on a vanilla (un-patched) Linux kernel (providing G-code simulation but no realtime machine control). If development files are installed for Xenomai (typically from package libxenomai-dev) or RTAI (typically from a package with a name starting "rtai-modules"), support for these real-time kernels will also be enabled.

--with-realtime=/usr/realtime-$VERSION
: Build for the RTAI realtime platform using the older "kernel realtime" model. This requires that you have an RTAI kernel and the RTAI modules installed in `/usr/realtime-$VERSION`. The resulting LinuxCNC executables will only run on the specified RTAI kernel. As of LinuxCNC 2.7, this produces the best realtime performance.

--enable-build-documentation
: Build the documentation, in addition to the executables. This option adds significantly to the time required for compilation, as building the docs is quite time consuming. If you are not actively working on the documentation you may want to omit this argument.

5.3.1.2 make arguments

The `make` command takes two useful optional arguments.

Parallel compilation
: `make` takes an optional argument `-jN` (where N is a number). This enables parallel compilation with N simultaneous processes, which can significantly speed up your build.

  A useful value for N is the number of CPUs in your build system. You can discover the number of CPUs by running `nproc`.

Building just a specific target
: If you want to build just a specific part of LinuxCNC, you can name the thing you want to build on the `make` command line. For example, if you are working on a component named `froboz`, you can build its executable by running:

```
> cd linuxcnc-dev/src
> make ../bin/froboz
```

5.3.2 Building Debian Packages

When building Debian packages, the LinuxCNC programs are compiled from source and then stored in a Debian package, complete with dependency information. This takes more time, and the programs can't be used until the Debian package is installed on a target machine.

This build mode is primarily useful when packaging the software for delivery to end users, and when building the software for a machine that doesn't have the build environment installed, or that doesn't have internet access.

Building Debian packages requires the `dpkg-buildpackage` tool, from the `dpkg-dev` package:

```
> sudo apt-get install dpkg-dev
```

Building Debian packages also requires that all build dependencies are installed, as described in the section Satisfying Build Dependencies.

Once those prerequisites are met, building the Debian packages consists of two steps.

The first step is generating the Debian package scripts and meta-data from the git repo by running this:

```
> cd linuxcnc-dev/debian
> ./configure uspace
> cd ..
```

Note
The `debian/configure` script is different from the `src/configure` script!
The `debian/configure` script needs different arguments depending on the platform you're building on/for, see the debian/-configure arguments section.

Once the Debian package scripts and meta-data are configured, build the package by running `dpkg-buildpackage` (note that it needs to run from the `linuxcnc-dev` directory, **not** from `linuxcnc-dev/debian`):

```
> dpkg-buildpackage -b -uc
```

5.3.2.1 `debian/configure` arguments

The `debian/configure` script configures the Debian packaging. It must be run before `dpkg-checkbuilddeps` and `dpkg-buildpackage` can be run.

It takes a single argument which specifies the realtime or non-realtime platform to build for. The normal values for this argument are:

`uspace`
: Configure the Debian package for Preempt-RT realtime or for non-realtime (these two are compatible).

`noauto`, `rtai`, `xenomai`
: Normally, the lists of RTOSes for uspace realtime to support is detected automatically. However, if you wish, you may specify one or more of these after `uspace` to enable support for these RTOSes. Or, to disable autodetection, specify `noauto`.

```
If you want just the traditional RTAI "kernel module" realtime, use
`-r` or `$KERNEL_VERSION` instead.
```

`rtai=<package name>`
: If the development package for rtai lxrt does not start with "rtai-modules", or if the first such package listed by apt-cache search is not the desired one, then explicitly specify the package name.

`-r`
: Configure the Debian package for the currently running RTAI kernel. You must be running an RTAI kernel on your build machine for this to work!

`$KERNEL_VERSION`
: Configure the debian package for the specified RTAI kernel version (for example "3.4.9-rtai-686-pae"). The matching kernel headers debian package must be installed on your build machine (for example "linux-headers-3.4.9-rtai-686-pae"). Note that you can *build* LinuxCNC in this configuration, but if you are not running the matching RTAI kernel you will not be able to *run* LinuxCNC, including the test suite.

5.4 Satisfying Build Dependencies

On Debian-based platforms we provide packaging meta-data that knows what external software packages need to be installed in order to build LinuxCNC. This is called the Build Dependencies of LinuxCNC. You can use this meta-data to easily list the required packages missing from your build system.

Debian systems provide a program called `dpkg-checkbuilddeps` that parses the package meta-data and compares the packages listed as build dependencies against the list of installed packages, and tells you what's missing.

First, install the `dpkg-checkbuilddeps` program by running:

```
> sudo apt-get install dpkg-dev
```

Then ask your LinuxCNC git checkout to generate its Debian package meta-data:

```
> cd linuxcnc-dev/debian
> ./configure uspace
> cd ..
```

Finally ask `dpkg-checkbuilddeps` to do its job (note that it needs to run from the `linuxcnc-dev` directory, **not** from `linuxcnc-dev/debian`):

```
> dpkg-checkbuilddeps
```

It will emit a list of packages that are required to build LinuxCNC on your system, but that are not installed yet. Install them all with `sudo apt-get install`, followed by the package names.

You can rerun `dpkg-checkbuilddeps` any time you want, to list any missing packages.

5.5 Setting up the environment

This section describes the special steps needed to set up a machine to run the LinuxCNC programs, including the tests.

5.5.1 Increase the locked memory limit

LinuxCNC tries to improve its realtime latency by locking the memory it uses into RAM. It does this in order to prevent the operating system from swapping LinuxCNC out to disk, which would have bad effects on latency.

Normally locking memory into RAM is frowned upon, and the operating system places a strict limit on how much memory a user is allowed to have locked.

When using the Preempt-RT realtime platform LinuxCNC runs with enough privilege to raise its memory lock limit itself. When using the RTAI realtime platform it does not have enough privilege, and the user must raise the memory lock limit.

If LinuxCNC displays the following message on startup, the problem is your system's configured limit on locked memory:

```
RTAPI: ERROR: failed to map shmem
RTAPI: Locked memory limit is 32KiB, recommended at least 20480KiB.
```

To fix this problem, add a file named `/etc/security/limits.d/linuxcnc.conf` (as root) with your favorite text editor (e.g., `sudo gedit /etc/security/limits.d/linuxcnc.conf`). The file should contain the following line:

```
* - memlock 20480
```

Log out and log back in to make the changes take effect. Verify that the memory lock limit is raised using the following command:

```
> ulimit -l
```

5.6 Options for checking out the git repo

The Quick Start instructions at the top of this document said to make an anonymous local clone from our git repo at http://github.com/-linuxcnc/linuxcnc.git. This is the quickest, easiest way to get started. However, there are other options to consider.

5.6.1 Fork us on Github

The LinuxCNC project git repo is at http://github.com/LinuxCNC/linuxcnc. github is a popular git hosting service and code sharing website. You can easily (and for no cost) create a fork of our git repo at github, and use that to track and publish your changes.

After creating your own github fork of LinuxCNC, clone it to your development machine and proceed with your hacking as usual.

We of the LinuxCNC project hope that you will share your changes with us, so that the community can benefit from your work. Github makes this sharing very easy: after you polish your changes and push them to your github fork, send us a Pull Request.

Chapter 6

Adding Configuration Selection Items

Example Configurations can be added to the Configuration Selector by two methods:

- Auxiliary applications — Applications installed independently with a deb package can place configuration subdirectories in a specified system directory. The directory name is specified using the shell linuxcnc_var script:

```
$ linuxcnc_var LINUXCNC_AUX_EXAMPLES
/usr/share/linuxcnc/aux_examples
```

- Runtime settings — the configuration selector can also offer configuration subdirectories specified at runtime using an exported environamental variable (LINUXCNC_AUX_CONFIGS). This variable should be a path list of one or more configuration directories separated by a (:). Typically, this variable would be set in a shell starting linuxcnc or in a user's ~/.profile startup script. Example:

```
export LINUXCNC_AUX_CONFIGS=~/myconfigs:/opt/otherconfigs
```

Chapter 7

Contributing to LinuxCNC

7.1 Introduction

This document contains information for developers about LinuxCNC infrastructure, and describes the best practices for contributing code and documentation updates to the LinuxCNC project.

Throughout this document, "source" means both the source code to the programs and libraries, and the source text for the documentation.

7.2 Communication among LinuxCNC developers

The two main ways that project developers communicate with each other are:

- Via IRC, at #linuxcnc-devel on FreeNode.
- Via email, on the developers' mailing list: https://lists.sourceforge.net/lists/listinfo/emc-developers

7.3 The LinuxCNC Source Forge project

We use Source Forge for mailing lists: http://sourceforge.net/p/emc/mailman/

7.4 The git Revision Control System

All of the LinuxCNC source is maintained in the revision control system git [1].

7.4.1 LinuxCNC official git repo

The official LinuxCNC git repo is at http://github.com/linuxcnc/linuxcnc/

Anyone can get a read-only copy of the LinuxCNC source tree via git:

```
git clone https://github.com/linuxcnc/linuxcnc linuxcnc-dev
```

If you are a developer with push access, then follow github's instructions for setting up a repository that you can push from.

[1] http://git-scm.com/

Note that the clone command put the local LinuxCNC repo in a directory called `linuxcnc-dev`, instead of the default `linuxcnc`. This is because the LinuxCNC software by default expects configs and G-code programs in a directory called `$HOME/linuxcnc`, and having the git repo there too is confusing.

Issues and pull requests are welcome on github: https://github.com/LinuxCNC/linuxcnc/issues https://github.com/LinuxCNC/linuxcnc/pulls

7.4.2 Use of git in the LinuxCNC project

We use the "merging upwards" and "topic branches" git workflows described here:

https://www.kernel.org/pub/software/scm/git/docs/gitworkflows.html

We have a development branch called `master`, and one or more stable branches with names like `2.6` and `2.7` indicating the version number of the releases we make from it.

Bugfixes go in the oldest applicable stable branch, and that branch gets merged into the next newer stable branch, and so on up to `master`. The committer of the bugfix may do the merges themselves, or they may leave the merges for someone else.

New features generally go in the `master` branch, but some kinds of features (specifically well isolated device drivers and documentation) may (at the discretion of the stable branch release managers) go into a stable branch and get merged up just like bugfixes do.

7.4.3 git tutorials

There are many excellent, free git tutorials on the internet.

The first place to look is probably the "gittutorial" manpage. This manpage is accessible by running "man gittutorial" in a terminal (if you have the git manpages installed). The gittutorial and its follow-on documentation are also available online here:

- git tutorial: https://www.kernel.org/pub/software/scm/git/docs/gittutorial.html
- git tutorial 2: https://www.kernel.org/pub/software/scm/git/docs/gittutorial-2.html
- Everyday git with 20 commands or so: https://www.kernel.org/pub/software/scm/git/docs/giteveryday.html
- Git User's Manual: https://www.kernel.org/pub/software/scm/git/docs/user-manual.html

For a more thorough documentation of git see the "Pro Git" book: http://git-scm.com/book

Another online tutorial that has been recommended is "Git for the Lazy": http://wiki.spheredev.org/Git_for_the_lazy

7.5 Overview of the process

The high-level overview of how to contribute changes to the source goes like this:

- Communicate with the project developers and let us know what you're hacking on
- Clone the git repo
- Make your changes in a local branch, making sure you "sign off" your commits according to our signed-off-by policy (see below).
- Adding documentation and tests is an important part of adding a new feature. Otherwise, others won't know how to use your feature, and if other changes break your feature it can go unnoticed without a test.
- Share your changes with the other project developers in one of these ways:
  - Push your branch to github and create a github pull request to https://github.com/linuxcnc/linuxcnc (this requires a github account)

  - Push your branch to a publicly visible git repo (such as github, bitbucket, your own publicly-accessible server, etc) and share that location on the emc-developers mailing list, or
  - Email your commits to the emc-developers mailing list (use `git format-patch` to create the patches)
- Advocate for your patch
  - Explain what problem it addresses and why it should be included in LinuxCNC
  - Be receptive to questions and feedback from the developer community.
  - It is not uncommon for a patch to go through several revisions before it is accepted.

7.6 git configuration

In order to be considered for inclusion in the LinuxCNC source, commits must have correct Author fields identifying the author of the commit. A good way to ensure this is to set your global git config:

`git config --global user.name "Your full name"`

`git config --global user.email "you@example.com"`

Use your real name (not a handle), and use an unobfuscated e-mail address.

7.7 Effective use of git

7.7.1 Commit contents

Keep your commits small and to the point. Each commit should accomplish one logical change to the repo.

7.7.2 Write good commit messages

Keep commit messages around 72 columns wide (so that in a default-size terminal window, they don't wrap when shown by `git log`).

Use the first line as a summary of the intent of the change (almost like the subject line of an e-mail). Follow it with a blank line, then a longer message explaining the change. Example:

```
Get rid of RTAPI_SUCCESS, use 0 instead

The test "retval < 0" should feel familiar; it's the same kind of
test you use in userspace (returns -1 for error) and in kernel space
(returns -ERRNO for error)
```

7.7.3 Commit to the proper branch

Bugfixes should go on the oldest applicable branch. New features should go in the master branch. If you're not sure where a change belongs, ask on irc or on the mailing list.

7.7.4 Use multiple commits to organize changes

When appropriate, organize your changes into a branch (a series of commits) where each commit is a logical step towards your ultimate goal. For example, first factor out some complex code into a new function. Then, in a second commit, fix an underlying bug. Then, in the third commit, add a new feature which is made easier by the refactoring and which would not have worked without fixing that bug.

This is helpful to reviewers, because it is easier to see that the "factor out code into new function" step was right when there aren't other edits mixed in; it's easier to see that the bug is fixed when the change that fixes it is separate from the new feature; and so on.

7.7.5 Follow the style of the surrounding code

Make an effort to follow the prevailing indentation style of surrounding code. In particular, changes to whitespace make it harder for other developers to track changes over time. When reformatting code must be done, do it as a commit separate from any semantic changes.

7.7.6 Simplify complicated history before sharing with fellow developers

With git, it's possible to record every edit and false start as a separate commit. This is very convenient as a way to create checkpoints during development, but often you don't want to share these false starts with others.

Git provides two main ways to clean history, both of which can be done freely before you share the change:

`git commit --amend` lets you make additional changes to the last thing you committed, optionally modifying the commit message as well. Use this if you realized right away that you left something out of the commit, or if you typo'd the commit message.

`git rebase --interactive upstream-branch` lets you go back through each commit made since you forked your feature branch from the upstream branch, possibly editing commits, dropping commits, or squashing (combining) commits with others. Rebase can also be used to split individual commits into multiple new commits.

7.7.7 Make sure every commit builds

If your change consists of several patches, `git rebase -i` may be used to reorder these patches into a sequence of commits which more clearly lays out the steps of your work. A potential consequence of reordering patches is that one might get dependencies wrong - for instance, introducing a use of a variable, and the declaration of that variable only follows in a later patch.

While the branch HEAD will build, not every commit might build in such a case. That breaks `git bisect` - something somebody else might use later on to find the commit which introduced a bug. So beyond making sure your branch builds, it is important to assure every single commit builds as well.

There's an automatic way to check a branch for each commit being buildable - see http://dustin.sallings.org/2010/03/28/git-test-sequence.html , and the code at https://github.com/dustin/bindir/blob/master/git-test-sequence . Use as follows (in this case testing every commit from origin/master to HEAD, including running regression tests):

```
cd linuxcnc-dev
git-test-sequence origin/master..  '(cd src && make && ../scripts/runtests)'
```

This will either report *All's well* or *Broke on <commit>*

7.7.8 Renaming files

Please use the ability to rename files very cautiously. Like running indent on single files, renames still make it more difficult to follow changes over time. At a minimum, you should seek consensus on irc or the mailing list that the rename is an improvement.

7.7.9 Prefer "rebase"

Use `git pull --rebase` instead of bare `git pull` in order to keep a nice linear history. When you rebase, you always retain your work as revisions that are ahead of origin/master, so you can do things like `git format-patch` them to share with others without pushing to the central repository.

7.8 Other ways to contribute

There are many ways to contribute to LinuxCNC, that are not addressed by this document. These ways include:

- Answering questions on the forum, mailing lists, and in IRC
- Reporting bugs on the bug tracker, forum, mailing lists, or in IRC
- Helping test experimental features

Chapter 8

Glossary

A listing of terms and what they mean. Some terms have a general meaning and several additional meanings for users, installers, and developers.

Acme Screw
A type of lead-screw that uses an Acme thread form. Acme threads have somewhat lower friction and wear than simple triangular threads, but ball-screws are lower yet. Most manual machine tools use acme lead-screws.

Axis
One of the computer controlled movable parts of the machine. For a typical vertical mill, the table is the X axis, the saddle is the Y axis, and the quill or knee is the Z axis. Angular axes like rotary tables are referred to as A, B, and C. Additional linear axes relative to the tool are called U, V, and W respectively.

Axis(GUI)
One of the Graphical User Interfaces available to users of LinuxCNC. It features the modern use of menus and mouse buttons while automating and hiding some of the more traditional LinuxCNC controls. It is the only open-source interface that displays the entire tool path as soon as a file is opened.

Gmoccapy (GUI)
A Graphical User Interfaces available to users of LinuxCNC. It features the use and feel of an industrial control and can be used with touch screen, mouse and keyboard. It support embedded tabs and hal driven user messages, it offers a lot of hal beens to be controled with hardware. Gmoccapy is highly cusomizable.

Backlash
The amount of "play" or lost motion that occurs when direction is reversed in a lead screw. or other mechanical motion driving system. It can result from nuts that are loose on leadscrews, slippage in belts, cable slack, "wind-up" in rotary couplings, and other places where the mechanical system is not "tight". Backlash will result in inaccurate motion, or in the case of motion caused by external forces (think cutting tool pulling on the work piece) the result can be broken cutting tools. This can happen because of the sudden increase in chip load on the cutter as the work piece is pulled across the backlash distance by the cutting tool.

Backlash Compensation
Any technique that attempts to reduce the effect of backlash without actually removing it from the mechanical system. This is typically done in software in the controller. This can correct the final resting place of the part in motion but fails to solve problems related to direction changes while in motion (think circular interpolation) and motion that is caused when external forces (think cutting tool pulling on the work piece) are the source of the motion.

Ball Screw
A type of lead-screw that uses small hardened steel balls between the nut and screw to reduce friction. Ball-screws have very low friction and backlash, but are usually quite expensive.

Ball Nut
A special nut designed for use with a ball-screw. It contains an internal passage to re-circulate the balls from one end of the screw to the other.

CNC
Computer Numerical Control. The general term used to refer to computer control of machinery. Instead of a human operator turning cranks to move a cutting tool, CNC uses a computer and motors to move the tool, based on a part program.

Comp
A tool used to build, compile and install LinuxCNC HAL components.

Configuration(n)
A directory containing a set of configuration files. Custom configurations are normally saved in the users home/linuxcnc/-configs directory. These files include LinuxCNC's traditional INI file and HAL files. A configuration may also contain several general files that describe tools, parameters, and NML connections.

Configuration(v)
The task of setting up LinuxCNC so that it matches the hardware on a machine tool.

Coordinate Measuring Machine
A Coordinate Measuring Machine is used to make many accurate measurements on parts. These machines can be used to create CAD data for parts where no drawings can be found, when a hand-made prototype needs to be digitized for moldmaking, or to check the accuracy of machined or molded parts.

Display units
The linear and angular units used for onscreen display.

DRO
A Digital Read Out is a system of position-measuring devices attached to the slides of a machine tool, which are connected to a numeric display showing the current location of the tool with respect to some reference position. DROs are very popular on hand-operated machine tools because they measure the true tool position without backlash, even if the machine has very loose Acme screws. Some DROs use linear quadrature encoders to pick up position information from the machine, and some use methods similar to a resolver which keeps rolling over.

EDM
EDM is a method of removing metal in hard or difficult to machine or tough metals, or where rotating tools would not be able to produce the desired shape in a cost-effective manner. An excellent example is rectangular punch dies, where sharp internal corners are desired. Milling operations can not give sharp internal corners with finite diameter tools. A *wire* EDM machine can make internal corners with a radius only slightly larger than the wire's radius. A *sinker* EDM can make internal corners with a radius only slightly larger than the radius on the corner of the sinking electrode.

EMC
The Enhanced Machine Controller. Initially a NIST project. Renamed to LinuxCNC in 2012.

EMCIO
The module within LinuxCNC that handles general purpose I/O, unrelated to the actual motion of the axes.

EMCMOT
The module within LinuxCNC that handles the actual motion of the cutting tool. It runs as a real-time program and directly controls the motors.

Encoder
A device to measure position. Usually a mechanical-optical device, which outputs a quadrature signal. The signal can be counted by special hardware, or directly by the parport with LinuxCNC.

Feed
Relatively slow, controlled motion of the tool used when making a cut.

Feed rate
The speed at which a cutting motion occurs. In auto or mdi mode, feed rate is commanded using an F word. F10 would mean ten machine units per minute.

Feedback
A method (e.g., quadrature encoder signals) by which LinuxCNC receives information about the position of motors

Feedrate Override
A manual, operator controlled change in the rate at which the tool moves while cutting. Often used to allow the operator to adjust for tools that are a little dull, or anything else that requires the feed rate to be “tweaked”.

Floating Point Number
A number that has a decimal point. (12.300) In HAL it is known as float.

G-Code
The generic term used to refer to the most common part programming language. There are several dialects of G-code, LinuxCNC uses RS274/NGC.

GUI
Graphical User Interface.

General
A type of interface that allows communications between a computer and a human (in most cases) via the manipulation of icons and other elements (widgets) on a computer screen.

LinuxCNC
An application that presents a graphical screen to the machine operator allowing manipulation of the machine and the corresponding controlling program.

HAL
Hardware Abstraction Layer. At the highest level, it is simply a way to allow a number of building blocks to be loaded and interconnected to assemble a complex system. Many of the building blocks are drivers for hardware devices. However, HAL can do more than just configure hardware drivers.

Home
A specific location in the machine’s work envelope that is used to make sure the computer and the actual machine both agree on the tool position.

ini file
A text file that contains most of the information that configures LinuxCNC for a particular machine.

Instance
One can have an instance of a class or a particular object. The instance is the actual object created at runtime. In programmer jargon, the Lassie object is an instance of the Dog class.

Joint Coordinates
These specify the angles between the individual joints of the machine. See also Kinematics

Jog
Manually moving an axis of a machine. Jogging either moves the axis a fixed amount for each key-press, or moves the axis at a constant speed as long as you hold down the key. In manual mode, jog speed can be set from the graphical interface.

kernel-space
See real-time.

Kinematics
The position relationship between world coordinates and joint coordinates of a machine. There are two types of kinematics. Forward kinematics is used to calculate world coordinates from joint coordinates. Inverse kinematics is used for exactly the opposite purpose. Note that kinematics does not take into account, the forces, moments etc. on the machine. It is for positioning only.

Lead-screw
An screw that is rotated by a motor to move a table or other part of a machine. Lead-screws are usually either ball-screws or acme screws, although conventional triangular threaded screws may be used where accuracy and long life are not as important as low cost.

Machine units
The linear and angular units used for machine configuration. These units are specified and used in the ini file. HAL pins and parameters are also generally in machine units.

MDI
Manual Data Input. This is a mode of operation where the controller executes single lines of G-code as they are typed by the operator.

NIST
National Institute of Standards and Technology. An agency of the Department of Commerce in the United States.

NML
Neutral Message Language provides a mechanism for handling multiple types of messages in the same buffer as well as simplifying the interface for encoding and decoding buffers in neutral format and the configuration mechanism.

Offsets
An arbitrary amount, added to the value of something to make it equal to some desired value. For example, gcode programs are often written around some convenient point, such as X0, Y0. Fixture offsets can be used to shift the actual execution point of that gcode program to properly fit the true location of the vise and jaws. Tool offsets can be used to shift the "uncorrected" length of a tool to equal that tool's actual length.

Part Program
A description of a part, in a language that the controller can understand. For LinuxCNC, that language is RS-274/NGC, commonly known as G-code.

Program Units
The linear and angular units used in a part program. The linear program units do not have to be the same as the linear machine units. See G20 and G21 for more information. The angular program units are always measured in degrees.

Python
General-purpose, very high-level programming language. Used in LinuxCNC for the Axis GUI, the Stepconf configuration tool, and several G-code programming scripts.

Rapid
Fast, possibly less precise motion of the tool, commonly used to move between cuts. If the tool meets the workpiece or the fixturing during a rapid, it is probably a bad thing!

Rapid rate
The speed at which a rapid motion occurs. In auto or mdi mode, rapid rate is usually the maximum speed of the machine. It is often desirable to limit the rapid rate when testing a g-code program for the first time.

Real-time
Software that is intended to meet very strict timing deadlines. Under Linux, in order to meet these requirements it is necessary to install a realtime kernel such as RTAI and build the software to run in the special real-time environment. For this reason real-time software runs in kernel-space.

RTAI
Real Time Application Interface, see https://www.rtai.org/, the real-time extensions for Linux that LinuxCNC can use to achieve real-time performance.

RTLINUX
See https://en.wikipedia.org/wiki/RTLinux, an older real-time extension for Linux that LinuxCNC used to use to achieve real-time performance. Obsolete, replaced by RTAI.

RTAPI
A portable interface to real-time operating systems including RTAI and POSIX pthreads with realtime extensions.

RS-274/NGC
The formal name for the language used by LinuxCNC part programs.

Servo Motor
Generally, any motor that is used with error-sensing feedback to correct the position of an actuator. Also, a motor which is specially-designed to provide improved performance in such applications.

Servo Loop
A control loop used to control position or velocity of an motor equipped with a feedback device.

Signed Integer
A whole number that can have a positive or negative sign. In HAL it is known as s32. (A signed 32-bit integer has a usable range of -2,147,483,647 to +2,147,483,647.)

Spindle
The part of a machine tool that spins to do the cutting. On a mill or drill, the spindle holds the cutting tool. On a lathe, the spindle holds the workpiece.

Spindle Speed Override
A manual, operator controlled change in the rate at which the tool rotates while cutting. Often used to allow the operator to adjust for chatter caused by the cutter's teeth. Spindle Speed Override assumes that the LinuxCNC software has been configured to control spindle speed.

Stepconf
An LinuxCNC configuration wizard. It is able to handle many step-and-direction motion command based machines. It writes a full configuration after the user answers a few questions about the computer and machine that LinuxCNC is to run on.

Stepper Motor
A type of motor that turns in fixed steps. By counting steps, it is possible to determine how far the motor has turned. If the load exceeds the torque capability of the motor, it will skip one or more steps, causing position errors.

TASK
The module within LinuxCNC that coordinates the overall execution and interprets the part program.

Tcl/Tk
A scripting language and graphical widget toolkit with which several of LinuxCNCs GUIs and selection wizards were written.

Traverse Move
A move in a straight line from the start point to the end point.

Units
See "Machine Units", "Display Units", or "Program Units".

Unsigned Integer
A whole number that has no sign. In HAL it is known as u32. (An unsigned 32-bit integer has a usable range of zero to 4,294,967,296.)

World Coordinates
This is the absolute frame of reference. It gives coordinates in terms of a fixed reference frame that is attached to some point (generally the base) of the machine tool.

Chapter 9

Legal Section

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9.2 GNU Free Documentation License

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Chapter 10

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