

Getting Started V2.8.1, 2020-12-01

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The LinuxCNC Team



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.

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Chapter 1

About LinuxCNC

1.1 The Software

- LinuxCNC (the Enhanced Machine Control) is a software system for computer control of machine tools such as milling machines and lathes, robots such as puma and scara and other computer controlled machines up to 9 axes.
- LinuxCNC is free software with open source code. Current versions of LinuxCNC are entirely licensed under the GNU General Public License and Lesser GNU General Public License (GPL and LGPL)
- LinuxCNC provides:
 - a graphical user interface (actually several interfaces to choose from)
 - an interpreter for *G-code* (the RS-274 machine tool programming language)
 - a realtime motion planning system with look-ahead
 - operation of low-level machine electronics such as sensors and motor drives
 - an easy to use *breadboard* layer for quickly creating a unique configuration for your machine
 - a software PLC programmable with ladder diagrams
 - easy installation with a Live-CD
- It does not provide drawing (CAD - Computer Aided Design) or G-code generation from the drawing (CAM - Computer Automated Manufacturing) functions.
- It can simultaneously move up to 9 axes and supports a variety of interfaces.
- The control can operate true servos (analog or PWM) with the feedback loop closed by the LinuxCNC software at the computer, or open loop with step-servos or stepper motors.
- Motion control features include: cutter radius and length compensation, path deviation limited to a specified tolerance, lathe threading, synchronized axis motion, adaptive feedrate, operator feed override, and constant velocity control.
- Support for non-Cartesian motion systems is provided via custom kinematics modules. Available architectures include hexapods (Stewart platforms and similar concepts) and systems with rotary joints to provide motion such as PUMA or SCARA robots.
- LinuxCNC runs on Linux using real time extensions.

1.2 The Operating System

LinuxCNC is available as ready-to-use packages for the Ubuntu and Debian distributions.

1.3 Getting Help

1.3.1 IRC

IRC stands for Internet Relay Chat. It is a live connection to other LinuxCNC users. The LinuxCNC IRC channel is #linuxcnc on freenode.

The simplest way to get on the IRC is to use the embedded java client on this [page](#).

SOME IRC ETIQUETTE

- Ask specific questions. . . Avoid questions like "Can someone help me?".
- If you're really new to all this, think a bit about your question before typing it. Make sure you give enough information so someone can solve your question.
- Have some patience when waiting for an answer, sometimes it takes a while to formulate an answer or everyone might be busy working or something.
- Set up your IRC account with your unique name so people will know who you are. If you use the java client, use the same name every time you log in. This helps people remember who you are and if you have been on before many will remember the past discussions which saves time on both ends.

Sharing Files The most common way to share files on the IRC is to upload the file to one of the following or a similar service and paste the link:

- *For text* - <http://pastebin.com/> , <http://pastie.org/> , <https://gist.github.com/>
- *For pictures* - <http://imagebin.org/> , <http://imgur.com/> , <http://bayimg.com/>
- *For files* - <https://filedropper.com/> , <http://filefactory.com/> , <http://1fichier.com/>

1.3.2 Mailing List

An Internet Mailing List is a way to put questions out for everyone on that list to see and answer at their convenience. You get better exposure to your questions on a mailing list than on the IRC but answers take longer. In a nutshell you e-mail a message to the list and either get daily digests or individual replies back depending on how you set up your account.

You can subscribe to the emc-users mailing list at: <https://lists.sourceforge.net/lists/listinfo/emc-users>

1.3.3 Web Forum

A web forum can be found at <https://forum.linuxcnc.org> or by following the link at the top of the linuxcnc.org home page.

This is quite active but the demographic is more user-biased than the mailing list. If you want to be sure that your message is seen by the developers then the mailing list is to be preferred.

1.3.4 LinuxCNC Wiki

A Wiki site is a user maintained web site that anyone can add to or edit.

The user maintained LinuxCNC Wiki site contains a wealth of information and tips at:

<http://wiki.linuxcnc.org>

1.3.5 Bug Reports

Report bugs to the LinuxCNC [github bug tracker](#).

Chapter 2

System Requirements

2.1 Minimum Requirements

The minimum system to run LinuxCNC and Debian / Ubuntu may vary depending on the exact usage. Stepper systems in general require faster threads to generate step pulses than servo systems. You can use the Live-CD to test the software before committing to a permanent installation on a computer. Keep in mind that the Latency Test numbers are more important than the processor speed for software step generation. More information on the Latency Test is [here](#). In addition LinuxCNC needs to be run on an operating system that uses a specially modified kernel. See [Kernel and Version Requirements](#)

Additional information is on the LinuxCNC Wiki site: [Hardware Requirements](#)

LinuxCNC and Debian Linux should run reasonably well on a computer with the following minimum hardware specification. These numbers are not the absolute minimum but will give reasonable performance for most stepper systems.

- 700 MHz x86 processor (1.2 GHz x86 processor recommended) or Raspberry Pi 4 or better.
- To run LinuxCNC 2.8 and Debian Buster from the LiveCD the system should be 64-bit capable.
- 512 MB or more of RAM
- 8 GB hard disk
- Graphics card capable of at least 1024x768 resolution, which is not using the NVidia or ATI fglrx proprietary drivers. Modern onboard graphic chipsets seem to generally be OK.
- A network or Internet connection (not strictly needed, but very useful for updates and for communicating with the LinuxCNC community)

Minimum hardware requirements change as Linux distributions evolve so check the [Debian](#) web site for details on the LiveCD you're using. Older hardware may benefit from selecting an older version of the LiveCD when available.

2.2 Kernel and Version requirements

LinuxCNC requires a kernel modified for realtime use to control real machine hardware. It can, however run on a standard kernel in simulation mode for purposes such as checking G-code, testing config files and learning the system. To work with these kernel versions there are two versions of LinuxCNC distributed. The package names are "linuxcnc" and "linuxcnc-uspace"

The realtime kernel options are preempt-rt, RTAI and Xenomai.

You can discover the kernel version of your system with the command

```
uname -a
```

If you see (as above) `-rt-` in the kernel name then you are running the preempt-rt kernel and should install the "uspace" version of linuxcnc. You should also install uspace for "sim" configs on non-realtime kernels

If you see `-rtai-` in the kernel name then you are running RTAI realtime. See below for the linuxcnc version to install.

2.2.1 Preempt-RT with linuxcnc-ospace

Preempt-RT is the newest of the realtime systems, and is also the version that is closest to a mainline kernel. Preempt-RT kernels are available as precompiled packages from the main repositories. The search term "PREEMPT_RT" will find them, and one can be downloaded and installed just like any other package. Preempt-RT will generally have the best driver support and is the only option for systems using the Mesa ethernet-connected hardware driver cards. In general preempt-rt has the worst latency of the available systems, but there are exceptions.

2.2.2 RTAI with linuxcnc

RTAI has been the mainstay of LinuxCNC distributions for many years. It will generally give the best realtime performance in terms of low latency, but might have poorer peripheral support and not as many screen resolutions. An RTAI kernel is available from the LinuxCNC package repository. If you installed from the Live/Install image then switching kernel and LinuxCNC flavour is described in [Installing-RTAI].

2.2.3 Xenomai with linuxcnc-ospace

Xenomai is also supported, but you will have to find or build the kernel and compile LinuxCNC from source to utilise it.

2.2.4 RTAI with linuxcnc-ospace

It is also possible to run linuxCNC with RTAI in user-space mode. As with Xenomai you will need to compile from source to do this.

2.3 Problematic Hardware

2.3.1 Laptops

Laptops are not generally suited to real time software step generation. Again a Latency Test run for an extended time will give you the info you need to determine suitability.

2.3.2 Video Cards

If your installation pops up with 800 x 600 screen resolution then most likely Debian does not recognize your video card or monitor. This can sometimes be worked-around by installing drivers or creating / editing Xorg.conf files.

Chapter 3

Getting LinuxCNC

This section describes the recommended way to download and make a fresh install of LinuxCNC. There are also [Alternate Install Methods](#) for the adventurous. If you have an existing install that you want to upgrade, go to the [Updating LinuxCNC](#) section instead.

Note

LinuxCNC requires a special kernel with real-time extensions. There are three possibilities here: preempt-rt, RTAI or Xenomai. In addition there are two versions of LinuxCNC which work with these kernels. See the table below for details.

Fresh installs of LinuxCNC are most easily created using the Live/Install Image. This is a hybrid ISO filesystem image that can be written to a USB storage device or a DVD and used to boot a computer. At boot time you will be given a choice of booting the "Live" system (to run LinuxCNC without making any permanent changes to your computer) or booting the Installer (to install LinuxCNC and its operating system onto your computer's hard drive).

The outline of the process looks like this:

1. Download the Live/Install Image.
2. Write the image to a USB storage device or DVD.
3. Boot the Live system to test out LinuxCNC.
4. Boot the Installer to install LinuxCNC.

3.1 Download the image

This section describes some methods for downloading the Live/Install Image.

3.1.1 Normal Download

For x86 PCs Download the Live/Install CD by clicking here:

<http://www.linuxcnc.org/iso/linuxcnc-2.8.0-buster.iso>

For the Raspberry Pi a complete SD card image is available here:

<http://www.linuxcnc.org/iso/linuxcnc-2.8.0-pi4.zip>

This can be installed using the normal Pi [install process](#) including with the Raspberry Pi Imager app.

3.1.2 Download using zsync

zsync is a download application that efficiently resumes interrupted downloads and efficiently transfers large files with small modifications (if you have an older local copy). Use zsync if you have trouble downloading the image using the [Normal Download](#) method.

ZSYNC IN LINUX

1. Install zsync using Synaptic or, by running the following in a [terminal](#)

```
sudo apt-get install zsync
```

2. Then run this command to download the iso to your computer

```
zsync http://www.linuxcnc.org/iso/linuxcnc-2.8.0-buster.iso.zsync
```

or

```
zsync http://www.linuxcnc.org/iso/linuxcnc-2.8.0-pi4.zip.zsync
```

zsync in Windows There is a Windows port of zsync. It works as a console application. It can be downloaded from:

<https://www.assembla.com/spaces/zsync-windows/documents>

3.1.3 Verify the image

(This step is unnecessary if you used zsync)

1. After downloading, verify the checksum of the image to ensure integrity.

```
md5sum linuxcnc-2.8.0-buster.iso
```

or

```
sha256sum linuxcnc-2.8.0-buster.iso
```

2. Then compare to these checksums

```
md5sum: 41b71c4956c0c89033a99a590ebaefec  
sha256sum: a542092aa9f399d3ad50bbb2f0f4dd63ad9332c23d8387f6061bdd186d1df3b0
```

Verify md5sum on Windows or Mac Windows and Mac OS X do not come with an md5sum program, but there are alternatives. More information can be found at: [How To MD5SUM](#)

3.2 Write the image to a bootable device

The Raspberry Pi image is a complete SD card image and should be written to an SD card in [the normal way](#)

The LinuxCNC Live/Install ISO Image is a hybrid ISO image which can be written directly to a USB storage device (flash drive) or a DVD and used to boot a computer. The image is too large to fit on a CD.

WRITING THE IMAGE TO A USB STORAGE DEVICE IN LINUX

1. Connect a USB storage device (for example a flash drive or thumb drive type device).
2. Determine the device file corresponding to the USB flash drive. This information can be found in the output of `dmesg` after connecting the device. `/proc/partitions` may also be helpful.

3. Use the `dd` command to write the image to your USB storage device. For example, if your storage device showed up as `/dev/sde`, then use this command:

```
dd if=linuxcnc-2.8.0-buster.iso of=/dev/sde
```

WRITING THE IMAGE TO A USB STORAGE DEVICE IN MAC OSX

1. Open a terminal and type

```
diskutil list
```

2. Insert the USB and note the name of the new disk that appears, eg `/dev/disk5`
3. unmount the USB. The number found above should be substituted in place of the N

```
diskutil unmountDisk /dev/diskN
```

4. Transfer the data with `dd`, as for Linux above. Note that the disk name has an added "r" at the beginning

```
sudo dd if=/path-to.iso of=/dev/rdiskN bs=1m
```

5. Note that this may take a long time to complete and there will be no feedback during the process.

WRITING THE IMAGE TO A DVD IN LINUX

1. Insert a blank DVD into your burner. A *CD/DVD Creator* or *Choose Disc Type* window will pop up. Close this, as we will not be using it.
2. Browse to the downloaded image in the file browser.
3. Right click on the ISO image file and choose *Write to Disc*.
4. Select the write speed. It is recommended that you write at the lowest possible speed.
5. Start the burning process.
6. If a *choose a file name for the disc image* window pops up, just pick OK.

WRITING THE IMAGE TO A DVD IN WINDOWS

1. Download and install Infra Recorder, a free and open source image burning program: <http://infrarecorder.org/>
2. Insert a blank CD in the drive and select *Do nothing* or *Cancel* if an auto-run dialog pops up.
3. Open Infra Recorder, and select the *Actions* menu, then *Burn image*.

WRITING THE IMAGE TO A DVD IN MAC OSX

1. Download the .iso file
2. Right-click on the file in the Finder window and select "Burn to disc" (The option to burn to disc will only appear if the machine has an optical drive fitted or connected)

3.3 Testing LinuxCNC

With the USB storage device plugged in or the DVD in the DVD drive, shut down the computer then turn the computer back on. This will boot the computer from the Live/Install Image and choose the Live boot option.

Note

If the system does not boot from the DVD or USB stick it might be necessary to change the boot order in the PC BIOS.

Once the computer has booted up you can try out LinuxCNC without installing it. You can not create custom configurations or modify most system settings in a Live session, but you can (and should) run the latency test.

To try out LinuxCNC: from the Applications/CNC menu pick LinuxCNC. A dialog box will open from which you can choose one of many sample configurations. At this point it only really makes sense to pick a "sim" configuration. Some of the sample configurations include onscreen 3D simulated machines, look for "Vismach" to see these.

To see if your computer is suitable for software step pulse generation run the Latency Test as shown [here](#).

At the time of writing the Live-Image is only available with the preempt-rt kernel and a matching LinuxCNC. On some hardware this might not offer good enough latency. There is an experimental version available using the RTAI realtime kernel which will often give better latency.

3.4 Installing LinuxCNC

To install LinuxCNC from the LiveCD select *Install (Graphical)* at bootup.

3.5 Updates to LinuxCNC

With the normal install the Update Manager will notify you of updates to LinuxCNC when you go on line and allow you to easily upgrade with no Linux knowledge needed. It is OK to upgrade everything except the operating system when asked to.

**Warning**

Do not upgrade the operating system if prompted to do so. You should accept OS *updates* however, especially security updates.

3.6 Install Problems

In rare cases you might have to reset the BIOS to default settings if during the Live CD install it cannot recognize the hard drive during the boot up.

3.7 Alternate Install Methods

The easiest, preferred way to install LinuxCNC is to use the Live/Install Image as described above. That method is as simple and reliable as we can make it, and is suitable for novice users and experienced users alike. However, this will typically replace any existing operating system.

In addition, for experienced users who are familiar with Debian system administration (finding install images, manipulating apt sources, changing kernel flavors, etc), new installs are supported on following platforms: ("amd64" means "64-bit", and is not specific to AMD processors, it will run on any 64-bit x86 system)

Distribution	Architecture	kernel	package name	Typical use
Debian Buster	amd64 & i386	Stock	linuxcnc-ospace	simulation only
Debian Buster	amd64 & armhf	preempt-rt	linuxcnc-ospace	machine control & simulation
Debian Buster	amd64	RTAI	linuxcnc	machine control (known issues)
Debian Jessie	amd64 & i386	Stock	linuxcnc-ospace	simulation only
Debian Wheezy	i386	RTAI	linuxcnc	machine control & simulation
Debian Wheezy	amd64 & i386	Preempt-RT	linuxcnc-ospace	machine control & simulation
Debian Wheezy	amd64 & i386	Stock	linuxcnc-ospace	simulation only
Ubuntu Precise	i386	RTAI	linuxcnc	machine control & simulation
Ubuntu Precise	amd64 & i386	Stock	linuxcnc-ospace	simulation only

Note

LinuxCNC v2.8 is not supported on Ubuntu Lucid or older.

Preempt-RT kernels The Preempt-rt kernels are available for Debian from the regular debian.org archive. The preempt-rt kernel for Raspberry Pi is available from the LinuxCNC repository. The package is called `linux-image-rt-*`. Simply install the package in the same way as any other package from the Synaptic Package manager or with `apt-get` at the command-line.

RTAI Kernels The RTAI kernels are available for download from the linuxcnc.org debian archive. The apt source is:

- Debian Buster: `deb http://linuxcnc.org buster base`
- Debian Wheezy: `deb http://linuxcnc.org wheezy base`
- Ubuntu Precise: `deb http://linuxcnc.org precise base`

Note

Debian Wheezy and Ubuntu Precise are both extremely old, and are out of their support period. It is strongly advised not to use either for a new install, and to seriously consider upgrading an existing installation.

The Buster / RTAI package is only available on amd64, but there are very few surviving systems that can not run a 64-bit OS.

**Warning**

There are known issues with the 64-bit RTAI 5.2 kernel with this version of LinuxCNC. The system will occasionally lock solid. However, this has, so far, been seen only during system exit. While running the system appears to be stable. But should nevertheless be considered experimental at this point.

Note

If you decide to use the RTAI 5.2 kernel and see a problem outside the circumstances described above then please report it immediately to the project developers.

3.7.1 Installing on Debian Buster (with Preempt-RT kernel)

1. Install Debian Buster (Debian 10), amd64 version. You can download the installer here: <https://www.debian.org/releases/-buster/>

2. After burning the iso and booting up if you don't want Gnome desktop select *Advanced Options > Alternative desktop environments* and pick the one you like. Then select *Install* or *Graphical Install*.

**Warning**

Do not enter a root password, if you do sudo is disabled and you won't be able to complete the following steps.

3. Run the following in a [terminal](#) to bring the machine up to date with the latest packages.

```
sudo apt-get update
sudo apt-get dist-upgrade
```

4. Install the Preempt-RT kernel and modules

```
sudo apt-get install linux-image-rt-amd64
```

5. Re-boot, and select the Linux 4.19.0-9-rt-amd64 kernel. This might be hidden in the "Advanced options for Debian Buster" sub-menu in Grub. When you log in, verify that `PREEMPT RT` is reported by the following command.

```
uname -v
```

6. Open Applications Menu > System > Synaptic Package Manager search for *linux-image* and right click on the original non-rt and select *Mark for Complete Removal*. Reboot. This is to force the system to boot from the RT kernel. If you prefer to retain both kernels then the other kernels need not be deleted, but grub boot configuration changes will be needed beyond the scope of this document.

7. Add the LinuxCNC Archive Signing Key to your apt keyring by running

```
sudo apt-key adv --keyserver hkp://keys.gnupg.net --recv-key 3cb9fd148f374fef
```

8. Add the apt repository:

```
echo deb http://linuxcnc.org/ buster base 2.8-rtpreempt | sudo tee -a /etc/apt/sources ↔
.list.d/linuxcnc.list
```

9. Update the package list from linuxcnc.org

```
sudo apt-get update
```

10. Install uspace (a reboot may be required prior to installing uspace)

```
sudo apt-get install linuxcnc-uspace
```

3.7.2 Installing on Debian Buster (with experimental RTAI kernel)

**Warning**

This kernel has known stability problems. It appears to run reliably once LinuxCNC is loaded. However kernel panics have been seen at system shut-down.

1. This kernel and LinuxCNC version can be installed on top of the LiveDVD install, or alternatively on a fresh Install of Debian Buster 64-bit as described above
-

2. Add the LinuxCNC Archive Signing Key to your apt keyring (Not necessary if switching the realtime mode of a LinuxCNC Live-CD image)

```
sudo apt-key adv --keyserver hkp://keys.gnupg.net --recv-key 3cb9fd148f374fef
```

3. Add the apt repository:

```
echo deb http://linuxcnc.org/ buster base 2.8-rt | sudo tee -a /etc/apt/sources.list.d ↵  
/linuxcnc.list
```

4. Update the package list from linuxcnc.org

```
sudo apt-get update
```

5. Install the RTAI kernel

```
sudo apt-get install linux-image-4.14.174-rtai-amd64
```

6. Install the RTAI application layer

```
sudo apt-get install rta-modules-4.14.174
```

7. Install linuxcnc (a reboot may be required prior to installing)

```
sudo apt-get install linuxcnc
```

3.7.3 Installing on Raspbian 10

1. Download a stock Raspbian image to an SD card and install in the [usual way](#)
2. Boot the Pi and open a terminal
3. Add the LinuxCNC Archive Signing Key to your apt keyring

```
sudo apt-key adv --keyserver hkp://keys.gnupg.net --recv-key 3cb9fd148f374fef
```

4. Add the apt repository:

```
echo deb http://linuxcnc.org/ buster base 2.8-rtpreempt | sudo tee -a /etc/apt/sources ↵  
.list.d/linuxcnc.list
```

5. Update the package list from linuxcnc.org

```
sudo apt-get update
```

6. install the realtime kernel

```
sudo apt-get install linux-image-4.19.71-rt24-v7l+
```

7. Install linuxcnc (a reboot may be required prior to installing)

```
sudo apt-get install linuxcnc-ospace
```


3.7.4 Installing on Ubuntu Precise

1. Install Ubuntu Precise 12.04 x86 (32-bit). Any flavor should work (regular Ubuntu, Xubuntu, Lubuntu, etc). 64-bit (AMD64) is currently not supported. You can download the installer here: <http://releases.ubuntu.com/precise/> Note the warnings that this release is out of support. But is a way to install LinuxCNC with a well-tested RTAI kernel.

2. Run the following to bring the machine up to date with the latest packages in Ubuntu Precise.

```
sudo apt-get update
sudo apt-get dist-upgrade
```

3. Add the LinuxCNC Archive Signing Key to your apt keyring by running

```
sudo apt-key adv --keyserver hkp://keys.gnupg.net --recv-key 3cb9fd148f374fef
```

4. Add a new apt source

```
sudo add-apt-repository "deb http://linuxcnc.org/ precise base 2.8-rt"
```

5. Fetch the package list from linuxcnc.org.

```
sudo apt-get update
```

6. Install the RTAI kernel and modules by running

```
sudo apt-get install linux-image-3.4-9-rtai-686-pae rtai-modules-3.4-9-rtai-686-pae
```

7. If you want to be able to build LinuxCNC from source using the git repo, also run

```
sudo apt-get install linux-headers-3.4-9-rtai-686-pae
```

8. Reboot, and make sure you boot into the rtai kernel. When you log in, verify that the kernel name is 3.4-9-rtai-686-pae.

```
uname -r
```

9. Run

```
sudo apt-get install linuxcnc
```

Chapter 4

Updating LinuxCNC

Updating LinuxCNC to a new minor release (ie to a new version in the same stable series, for example from 2.7.0 to 2.7.1) is an automatic process if your PC is connected to the internet. You will see an update prompt after a minor release along with other software updates. If you don't have an internet connection to your PC see [Updating without Network](#).

4.1 Upgrade to the new version

This section describes how to upgrade LinuxCNC from version 2.7 to the new 2.8.0 version. It assumes that you have an existing 2.7 install that you want to update.

To upgrade LinuxCNC from a version older than 2.7, you have to first [upgrade your old install to 2.7](#), then follow these instructions to upgrade to the new version.

If you do not have an old version of LinuxCNC to upgrade, then you're best off making a fresh install of the new version as described in the section [Getting LinuxCNC](#).

Furthermore, if you are running Ubuntu Precise or Debian Wheezy it is well worth considering making a backup of the "linuxcnc" directory on removeable media and performing a [clean install of a newer OS and LinuxCNC version](#) as these releases were EOL in 2017 and 2018 respectively. If you are running on Ubuntu Lucid then you will have to do this, as Lucid is no longer supported by LinuxCNC (it was EOL in 2013)

To upgrade major versions like 2.7 to 2.8 when you have a network connection at the machine you need to disable the old linuxcnc.org apt sources and add a new linuxcnc.org apt source for 2.7, then upgrade LinuxCNC.

The details will depend on which platform you're running on. Open a [terminal](#) then type `lsb_release -ic` to find this information out:

```
lsb_release -ic
Distributor ID: Debian
Codename:       wheezy
```

You should be running on Debian Stretch or Wheezy (as above), or Ubuntu Precise. Packages are also available for Debian Jessie or Debian Buster if you happen to already be running one of those.

You will also need to check which realtime kernel is being used:

```
uname -r
4.19.0-9-rt-amd64
```

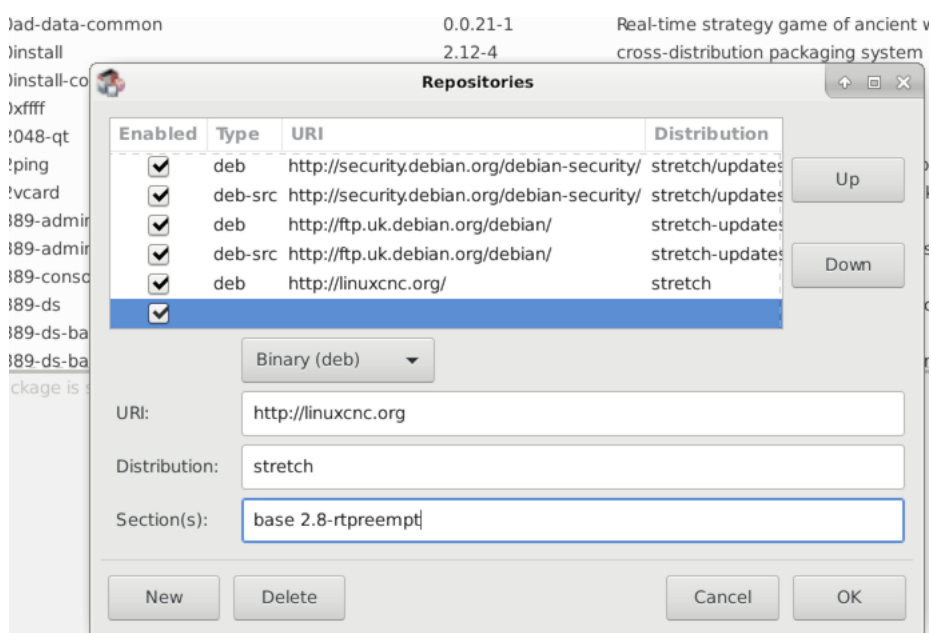
If you see (as above) `-rt-` in the kernel name then you are running the preempt-rt kernel and should install the "uspace" version of linuxcnc. You should also install uspace for "sim" configs on non-realtime kernels

If you see `-rtai-` in the kernel name then you are running RTAI realtime. See below for the linuxcnc version to install.

4.1.1 Setting apt sources

- Open the `Software Sources` window. The process for doing this differs slightly on the three supported platforms:
 - Debian:
 - * Click on `Applications Menu`, then `System`, then `Synaptic Package Manager`.
 - * In `Synaptic`, click on the `Settings` menu, then click `Repositories` to open the `Software Sources` window.
 - Ubuntu:
 - * Click on the `Dash Home` icon in the top left.
 - * In the `Search` field, type "software", then click on the `Ubuntu Software Center` icon.
 - * In the `Ubuntu Software Center` window, click on the `Edit` menu, then click on `Software Sources...` to open the `Software Sources` window.
- In the `Software Sources` window, select the `Other Software` tab.
- Delete or un-check all the old `linuxcnc.org` entries (leave all non-`linuxcnc.org` lines as they are).
- Click the `Add` button and add a new apt line. The line will be slightly different on the different platforms:

Platform	apt source line
Debian Stretch	deb http://linuxcnc.org stretch base 2.8-rtpreempt
Debian Wheezy	deb http://linuxcnc.org wheezy base 2.8-rt
Ubuntu Precise	deb http://linuxcnc.org precise base 2.8-rt
Debian Jessie - preempt	deb http://linuxcnc.org jessie base 2.8-rtpreempt
Debian Jessie - RTAI	deb http://linuxcnc.org jessie base 2.8-rt
Debian Buster - preempt	deb http://linuxcnc.org buster base 2.8-rtpreempt
Debian Buster - RTAI	deb http://linuxcnc.org buster base 2.8-rt



- Click `Add Source`, then `Close` in the Software Sources window. If it pops up a window informing you that the information about available software is out-of-date, click the `Reload` button.

4.1.2 Upgrading to the new version

Now your computer knows where to get the new version of the software, next we need to install it.

The process again differs depending on your platform.

4.1.2.1 Debian Wheezy & Stretch and Ubuntu Lucid

Debian Wheezy and Stretch both use the Synaptic Package Manager.

- Open Synaptic using the instructions in [Setting apt sources](#) above.
- Click the `Reload` button.
- Use the Search function to search for `linuxcnc`.
- The package is called "linuxcnc" for RTAI kernels and "linuxcnc-uspace" for preempt-rt.
- Click the check box to mark the new linuxcnc and linuxcnc-doc-* packages for upgrade. The package manager may select a number of additional packages to be installed, to satisfy dependencies that the new linuxcnc package has.
- Click the `Apply` button, and let your computer install the new package. The old linuxcnc package will be automatically upgraded to the new one.

4.1.3 Ubuntu Precise

- Click on the `Dash Home` icon in the top left.
- In the `Search` field, type "update", then click on the `Update Manager` icon.
- Click the `Check` button to fetch the list of packages available.
- Click the `Install Updates` button to install the new versions of all packages.

4.2 Updating without Network

To update without a network connection you need to download the deb then install it with `dpkg`. The debs can be found in <http://linuxcnc.org/dists/> You have to drill down from the above link to find the correct deb for your installation. Open a [terminal](#) and type in `lsb_release -ic` to find the name of your OS.

```
> lsb_release -ic
Distributor ID: Debian
Codename:      buster
```

Pick the OS from the list then pick the major version you want like 2.8-rt for RTAI or 2.8-rtpreempt for preempt-rt.

Next pick the type of computer you have: `binary-amd64` for any 64-bit x86, `binary-i386` for 32 bit, `binary-armhf` for RaspBerry Pi.

Next pick the version you want from the bottom of the list like `linuxcnc-uspace_2.8.0_amd64.deb`. (choose the latest by date) Download the deb and copy it to your home directory. You can rename the file to something a bit shorter with the file manager like `linuxcnc_2.8.0.deb` then open a terminal and install it with the package manager with this command:

```
sudo dpkg -i linuxcnc_2.8.0.deb
```

4.3 Updating Configuration Files (for 2.8.x)

The new version of LinuxCNC differs from version 2.7 in some ways that may require changes to your machine configuration.

The main difference is that LinuxCNC no longer makes any assumptions about which joint controls which axis. This change is generally termed "joints-axes" after the name of the development branch where the changes started. This change has been in development since at least 2010, and has finally been merged.

4.3.1 Distribution Configurations (updates for joints_axes)

The LinuxCNC distribution includes many example configurations organized in directory hierarchies named: `by_machine`, `by_interface`, and `sim` (simulated machines). These configurations are often used as starting points for making a new configuration, as examples for study, or as complete simulated machines that can run without special hardware or real-time kernels.

The configuration files in these directory trees have been updated for the changes required for the `joints_axes` updates.

4.3.2 Automatic updates (update_ini script for joints_axes)

Since the `joints_axes` updates require a number of changes to user ini files and their related halfiles, a script named `update_ini` is provided to automatically convert user configurations.

This script is invoked when a user starts an existing configuration for the first time after updating LinuxCNC. The script searches the user ini file for a `[EMC]VERSION` item. If this item 1) does not exist, or 2) exists and is set to the historical CVS value `"$Revision$"`, or is a numerical value less than 1.1, then the `update_ini` script will popup a dialog to offer to edit the user files to create an updated configuration. If the user accepts, the configuration will be updated.

For example, if the user configuration is named `bigmill.ini`, the `bigmill.ini` file and its local associated hal files will be edited to incorporate `joints_axes` changes. All files of the initial configuration will be saved in a new directory named after the original configuration with a `".old"` suffix (`bigmill.old` in the example).

The `update_ini` script handles all common user items that are found in basic machines employing identity kinematics. Less common items used in more complex machines may not be converted automatically. Examples of complex machine configurations include:

- gantries with two joints for an axis
- machines with jogwheels
- robots with non-identity kinematics
- configurations using `haltel` files

The following subsections and the section for *Hal Changes* list items that may require additional user edits to ini or hal files.

4.3.3 Multiple Spindle Support

LinuxCNC now supports up to 8 spindles (and can be recompiled for more) Existing G-code will run without modification and most configurations will default to single spindles. To specify more than one spindle set the `[TRAJ]SPINDLES=` entry in the INI file **and** include the `num_spindles=` parameter for the motion module (set with either `[EMCMOT]EMCMOT = motmod` `num_spindles=` or included in a halfile `loadrt` entry for `motmod`).

The motion module `num_spindles=` parameter and the `[TRAJ]SPINDLES=` settings **must** match.

The spindle control pin names have been changed to make spindles look more like axes and joints. `motion.spindle-speed-out` is now `spindle.0.speed-out` for example. The automatic update script will take care of these changes. To control extra spindles the G and M-codes which control spindle speed now accept an additional "\$" argument, for example `M3 $2` to start the third spindle. "\$" was chosen to avoid clashes with any existing code letters. It should be possible to create custom G-codes to match any other multi-spindle controller. See the G-code and M-code manuals for code changes, and `man motion` for the HAL pin changes.

4.3.4 TRAJ velocities, accelerations names

With incorporation of joints_axes functionality, some names were changed to clarify available functionality.

```
was: [TRAJ]MAX_VELOCITY           is: [TRAJ]MAX_LINEAR_VELOCITY
was: [TRAJ]DEFAULT_VELOCITY       is: [TRAJ]DEFAULT_LINEAR_VELOCITY

was: [TRAJ]MAX_ACCELERATION       is: [TRAJ]MAX_LINEAR_ACCELERATION
was: [TRAJ]DEFAULT_ACCELERATION   is: [TRAJ]DEFAULT_LINEAR_ACCELERATION
```

4.3.5 Kinematics modules

The gentrivkins and gantrykins kinematics modules have been removed as their functionality is now available in the updated trivkins module.

The gentrivkins module has only been available in prior joints_axes branches. To convert, it is necessary to change the name.

Hal file examples:

```
was: loadrt gentrivkins
is: loadrt trivkins

was: loadrt gentrivkins coordinates=xxyz
is: loadrt trivkins      coordinates=xxyz
```

Configurations using gantrykins should be updated to use trivkins with the kinstype= parameter set to BOTH (for KINEMATICS_BOTH).

Hal file example:

```
was: loadrt gantrykins coordinates=xxyz
is: loadrt trivkins      coordinates=xxyz kinstype=BOTH
```

See the trivkins man page for additional information (*\$ man trivkins*)

Note: the most supported usage for specifying kinematics in joints_axes is to set values in the configuration ini file [KINS] section and then reference them within the specified [HAL]HALFILES (.hal .tcl files). For example:

```
infile:      [KINS]
             KINEMATICS = trivkins
             JOINTS = 3
             ...

halfile:      loadrt [KINS]KINEMATICS

haltclfile:   loadrt $::KINS(KINEMATICS)
```

4.3.6 Lathe Configurations

Prior to joints_axes incorporation, lathes were often configured as if they were three axis (XYZ) machines with an unused axis (Y). This was convenient for sharing Hal files (especially for simulation configs) but required specification of [TRAJ]AXES =3, a *dummy* AXIS_Y section, and provisions for homing the unused Y coordinate. These arrangements are no longer required or recommended.

Historical lathe configurations used the default options for the trivkins kinematics module. These default options configure all axis letters (XYZABCUVW). With joints_axes incorporation, a more appropriate kinematics specification sets the coordinates to the exact ones used (XZ) and sets the number of joints accordingly to 2. There is no need for an ini file [AXIS_Y] section and only two [JOINT_N] sections need be defined.

Example ini file items for a lathe (only sections relevant to kinematics are shown):

```
[KINS]
KINEMATICS = trivkins coordinates=xz
JOINTS = 2

[TRAJ]
COORDINATES = XZ
...

[AXIS_X]
...

[AXIS_Z]
...

[JOINT_0]
...

[JOINT_1]
...
```

Note that some simulation configurations may still use the historical lathe configuration precedents.

4.3.7 Consistent Joints/Axes specifications

Ini file items that affect joints and axes usage must be consistent.

The motion kinematics module typically loaded with *[KINS]KINEMATICS=* must use a number of joints equal to the number specified with *[KINS]JOINTS=*.

The kinematics module must implement axis letters that are consistent with the specification used by the task module item *[TRAJ]COORDINATES=*.

Examples:

Three axis Cartesian machine using trivkins (KINEMATICS_IDENTITY):

```
[KINS]KINEMATICS = trivkins
[KINS]JOINTS      = 3
[TRAJ]COORDINATES = XYZ
```

Two axis lathe using trivkins (KINEMATICS_IDENTITY) with non-consecutive axis letters:

```
[KINS]KINEMATICS = trivkins coordinates=XZ
[KINS]JOINTS      = 2
[TRAJ]COORDINATES = XZ
```

Gantry using trivkins with duplicated axis letters and KINEMATICS_BOTH to allow individual joint positioning (for homing):

```
[KINS]KINEMATICS = trivkins coordinates=XYZZ kinstype=BOTH
[KINS]JOINTS      = 4
[TRAJ]COORDINATES = XYZZ
```

Gantry using trivkins (KINEMATICS_BOTH) with duplicated axis letters and a rotary axis with skipped axis letters (A,B skipped):

```
[KINS]KINEMATICS = trivkins coordinates=XYZZC kinstype=BOTH
[KINS]JOINTS      = 5
[TRAJ]COORDINATES = XYZZC
```

Linear Delta Robot with non-identity kins (KINEMATICS_BOTH) working in Cartesian frame with an additional rotary coordinate:

```
[KINS]KINEMATICS = lineardeltakins
[KINS]JOINTS      = 4
[TRAJ]COORDINATES = XYZA
```

Note: Some general-purpose kinematics modules (like *trivkins*) implement identity kinematics with support for coordinate specification (axis letters). Axis letters may be omitted. Axis letters may be duplicated. Joints are assigned to axis letters in a defined manner (*\$ man trivkins*).

Note: For *trivkins* module loading, do not include spaces about the = sign or letters:

```
This:      [KINS]KINEMATICS = trivkins coordinates=XZ
NOT This:  [KINS]KINEMATICS = trivkins coordinates = X Z
```

Note: Custom kinematics modules that implement non-identity kinematics (like *lineardeltakins*) define machine-specific relationships between a set of coordinates and a set of joints. Typically, custom kinematics modules compute the joints-axes relationships within the custom module but it is important to use consistent settings for the related ini items: *[KINS]JOINTS* and *[TRAJ]COORDINATES*. The details will usually be explained in the module man page (for example, *\$ man lineardeltakins*).

4.3.8 Home sequences

Negative values may be used for the ini file items named *[JOINT_n]HOME_SEQUENCE*. Prior to *joints_axes* incorporation a value of -1 or the omission of the item indicated no sequence was applicable. Now, only omission of the item is used for that purpose. See the chapter: [Homing Configuration](#) for more information.

4.3.9 Locking rotary indexer (updates for *joints_axes*)

With *joints_axes*, an indexer is a joint that can be homed (joint mode) but must also be unlocked from gcode. This requires a one-to-one correspondence between a single joint and an axis.

Specify the joint number that corresponds to a rotary axis (L = A,B, or C) with an ini file setting for the axis:

```
[AXIS_L]LOCKING_INDEXER_JOINT = joint_number_for_indexer
```

Specify that the joint is a locking indexer with an ini file setting for the joint (N is the *joint_number_for_indexer*):

```
[JOINT_N]LOCKING_INDEXER = 1
```

Hal pins can be created to coordinate use of a locking indicator joint:

```
joint.N.unlock      (BIT output from Hal)
joint.N.is-unlocked (BIT input to   Hal)
```

To create these hal pins for locking joints, specify all joints that are used as locking indexers with the *unlock_joints_mask* parameter for the *motmod* module. (bit0(LSB)==>joint0, bit1==>joint1, etc.)

```
[EMCMOT]
EMCMOT = motmod unlock_joints_mask=BITMASK
```

As an example, consider a machine using *trivkins* kinematics with coordinates XYZB where B is a locking indexer. For *trivkins*, joint numbers (starting with 0) are assigned consecutively to the coordinates specified (axis coordinate letters may be omitted). For this example, X==>joint0, Y==>joint1, Z==>joint2, B==>joint3. The mask to specify joint 3 is 000001000 (binary) == 0x08 (hexadecimal)

The required ini file entries for this *trivkins* XYZB example are:


```
[KINS]
JOINTS = 4
KINEMATICS = trivkins coordinates=XYZB
...

[TRAJ]
COORDINATES = XYZB
...

[EMCMOT]
EMCMOT = motmod unlock_joints_mask=0x08
...

[AXIS_B]
LOCKING_INDEXER_JOINT = 3
...

[JOINT_3]
LOCKING_INDEXER = 1
...
```

For more complex kinematics, select the joint number as required — there must be a one-to-one correspondence between the rotary axis and the joint number.

(See the motion man page (*\$ man motion*) for more information on motmod)

4.3.10 Stricter INI file syntax

Lines with numeric INI variables are no longer allowed to have trailing text. In earlier versions of LinuxCNC any text after the number was silently ignored, but as of this version such text is totally disallowed. This includes hash characters ("**#**"), which in this position are a part of the value, not a comment character.

For example, lines like this will no longer be accepted:

```
MAX_VELOCITY = 7.5 # This is the max velocity of the axis.
```

They could be transformed into pairs of lines like this:

```
# This is the max velocity of the axis.
MAX_VELOCITY = 7.5
```

4.3.11 [TRAJ] settings

In 2.7.x versions, trajectory planning ([TRAJ]) settings included:

```
[TRAJ]
DEFAULT_ACCELERATION
MAX_ACCELERATION
```

Interim work prepared for distinct linear and angular items by renaming these items as:

```
[TRAJ]
DEFAULT_LINEAR_ACCEL
MAX_LINEAR_ACCEL
```

As these abbreviated names were inconsistent with other name conventions and the implementation of the `update_ini` script, the interim naming has been corrected to use:

```
[TRAJ]
DEFAULT_LINEAR_ACCELERATION
MAX_LINEAR_ACCELERATION
```

Note

Support for specifying trajectory planning angular default and maximum accelerations has not been implemented.

4.4 Hal Changes (updates for joints_axes 2.8.x)

4.4.1 Wheel or MPG (manual pulse generator) jogging

Prior to incorporation of joints_axes updates, wheel jogging was supported in joint mode only and controlled with hal pins:

```
bit    IN    axis.M.jog-enable
float  IN    axis.M.jog-scale
s32    IN    axis.M.jog-counts
bit    IN    axis.M.jog-vel-mode
```

where *M* is a number corresponding to an axis letter (0==>X, 1==>Y, etc.)

With incorporation of joints_axes updates, wheel jogging is available for joints in joint mode and for each axis coordinate in teleop mode. The controlling hal pins provided are:

```
bit    IN    joint.N.jog-enable
float  IN    joint.N.jog-scale
s32    IN    joint.N.jog-counts
bit    IN    joint.N.jog-vel-mode

bit    IN    axis.L.jog-enable
float  IN    axis.L.jog-scale
s32    IN    axis.L.jog-counts
bit    IN    axis.L.jog-vel-mode
```

where *N* is a joint number and *L* is an axis letter.

To use an MPG in identity kins configurations where there is a one-to-one correspondence of a joint number and an axis letter, it may be convenient to connect the corresponding hal pins. For example, if joint 1 corresponds exactly to axis letter y:

```
net jora_1_y_enable => joint.1.jog-enable => axis.y.jog-enable
net jora_1_y_scale  => joint.1.jog-scale  => axis.y.jog-scale
net jora_1_y_counts => joint.1.jog-counts => axis.y.jog-counts
net jora_1_y_vel-mode => joint.1.jog-vel-mode => axis.y.jog-vel-mode
```

(The signal names jora_1_y_* are examples, names prior to conversion for joints_axes will depend upon the specific configuration details.)

Configurations with non-identity kinematics and configurations that use duplicated axis letters (for example, gantries using more than one joint for an axis coordinate) will require appropriate independent control logic to support both joint and teleop (world) jogging.

4.4.2 Ini Hal pins

Hal pins are created for ini file items for both joints ([JOINT_N] stanzas) and axes ([AXIS_L] stanzas):

```

For N = 0 ... [KINS] (JOINTS -1)
Ini File Item          hal pin name
[JOINT_N]BACKLASH      ini.N.backlash
[JOINT_N]FERROR        ini.N.ferror
[JOINT_N]MIN_FERROR    ini.N.min_ferror
[JOINT_N]MIN_LIMIT     ini.N.min_limit
[JOINT_N]MAX_LIMIT     ini.N.max_limit
[JOINT_N]MAX_VELOCITY  ini.N.max_velocity
[JOINT_N]MAX_ACCELERATION ini.N.max_acceleration
[JOINT_N]HOME          ini.N.home
[JOINT_N]HOME_OFFSET   ini.N.home_offset

```

```

For L = x y z a b c u v w:
Ini File Item          hal pin name
[AXIS_L]MIN_LIMIT      ini.L.min_limit
[AXIS_L]MAX_LIMIT      ini.L.max_limit
[AXIS_L]MAX_VELOCITY   ini.L.max_velocity
[AXIS_L]MAX_ACCELERATION ini.L.max_acceleration

```

Note: In prior versions of LinuxCNC (before `joints_axes` updates), the hal pin names `ini.N.*` referred to axes with `0==>x`, `1==>y`, etc. (pins were created for all 9 axes) See the man page (`$ man milltask`) for more information

4.5 Hal Changes (Other 2.8.x)

4.5.1 halcompile

The number of names= instances was formerly limited to 16. Now, for realtime components (loadrt) the instances are assigned dynamically with no built-in limit. The limit of 16 still applies to names= items for userspace (loadusr) components.

For components using *personality*, the maximum number is now settable by a command line option `-Pl--personalities`.

4.5.2 Parameter to Pin changes

The following hal output pins were changed from parameters to pins so that they can be connected to signals:

```

motion.servo.last-period      (servo last period in clks)
motion.servo.last-period_ns   (kernel-dependent availability)

```

4.6 Interface changes for joints_axes 2.8.x

4.6.1 python linuxcnc module

The `jog()` interface includes a *joint-flag* to specify joint (True) or teleop (False) jogging:

```

jog(command, joint-flag, axis-or-joint-number, velocity[, distance])

jog(linuxcnc.JOG_STOP, joint-flag, axis-or-joint-number)
jog(linuxcnc.JOG_CONTINUOUS, joint-flag, joint-flag, velocity)
jog(linuxcnc.JOG_INCREMENT, joint-flag, axis-or-joint-number, velocity, distance)

```

4.7 GUIs (updates for joints_axes 2.8.x)

4.7.1 Notes on joint/axis jogging, homing, and kinematics

With incorporation of joints_axes updates, LinuxCNC enforces the distinctions of joints and axes (coordinate letters) — but some guis (like the axis gui) may hide some of the distinctions for simple machines.

In most cases, you can think of joints as *motors*.

The relationships between joints and axis coordinates are determined by the mathematical kinematics functions that describe a machine's motion.

World coordinates (X,Y,Z,A,B,C,U,V,W) are determined by applying *FORWARD* kinematics operations to joint (motor) positions.

When moving in world space (e.g., gcode movements) the required joint (motor) positions are determined by applying *INVERSE* kinematics operations to the coordinates requested for motion in world space.

Moving in world space is possible only *after* homing.

For simple machines (like mills and lathes) there is a one-to-one equivalence of joints and axis coordinate letters. For example, on an XYZ mill, the relationships are typically: axisX==joint0, axisY==joint1, axisZ==joint2. This correspondence is characterized as *IDENTITY* kinematics and the kinematics module used is usually trivkins (trivial kinematics). (See the trivkins man page `$ man trivkins`)

Joint jogging (by joint number 0,1,...) is used in joint mode (usually used only *BEFORE* homing). When homing is completed, the jogging mode is *AUTOMATICALLY* switched from joint mode to world mode and axis jogging (coordinate letter X,Y,...) is used. This is appropriate for all gcode moves requested by MDI commands or by gcode programs.

Although jogging in joint mode is often never required after homing, some guis (like axis) provide a keyboard shortcut (\$) to allow toggling between joint and world (teleop) modes for machines that use *non-IDENTITY* kinematics.

In many common situations, joint jogging is never needed since homing is accomplished using home switches and/or the various homing methods provided by LinuxCNC. One simply turns on the machine, issues the Home-All command, the machine homes and changes to world mode automatically. See [Homing Configuration](#)

Machines that do not use home switches may require manual jogging in joint mode before homing each and every joint. It is also possible to use immediate homing (see the homing docs) for joints that do not require homing to a fixed position.

Although a gui may hide joints/axes distinctions for *IDENTITY* kinematics machines, it is usually important to complete homing in order to run programs or use features provided by a gui.

By default, the trivkins module declares itself as having *IDENTITY* kinematics. The distinctions of joint/world operations can be made visible in the axis gui when using trivkins by setting the kinematics type to a *non-IDENTITY* type using `kinstype=both`. The *both* setting indicates that both forward and inverse kinematics functions are available and gui provisions that hide the distinctions of joints and axis letters should not be employed. For example, for an xyz configuration, specify:

```
[KINS]
KINEMATICS = trivkins coordinates=xyz kinstype=both
```

With this setting, identity kinematics will be used but the axis gui will:

1. show joint numbers prior to homing
2. show axis letters after successful homing
3. support toggling between joint and teleop modes with the \$ key

4.7.2 Halui

Halui now supports teleop jogging resulting in some changed pin names and numerous new names for jogging-related pins.

See the man page (`$ man halui`) for all pin names.

4.7.2.1 TELEOP jogging (also called axis or world jogging)

New pins for teleop jogging are:

```
new: halui.axis.jog-speed
new: halui.axis.jog-deadband

new: halui.axis.L.plus
new: halui.axis.L.minus
... etc.
```

where *L* is a letter corresponding to one of the axis letters specified by [TRAJ]COORDINATES or *selected* for the axis selected by the halui.axis.L.select pins.

4.7.2.2 Joint jogging

All pins for joint jogging were renamed for specificity:

```
was: halui.jog-speed          is: halui.joint.jog-speed
was: halui.jog-deadband       is: halui.joint.jog-deadband

was: halui.jog.N.plus         is: halui.joint.N.plus
was: halui.jog.N.minus        is: halui.joint.N.minus
... etc.                     ... etc.
```

where *N* is a joint number (0 ... num_noints-1) or *selected* for the joint selected by the halui.joint.N.select pins.

4.7.2.3 Additional pin renames

The hal pins for *selected* joints were renamed for consistency with related pins.

```
was: halui.joint.selected.is_homed
is: halui.joint.selected.is-homed

was: halui.joint.selected.on-soft-limit
is: halui.joint.selected.on-soft-min-limit
```

4.7.3 AXIS GUI

4.7.3.1 Identity Kinematics

The axis gui continues to support identity kinematics configurations. This gui hides the distinctions of axes and joints in order to simplify the display and usage of simple machines.

4.7.3.2 Special case kinematics

Some machines, typically gantrys, may use a configuration with more than one joint assigned to an axis letter. This can be done with the trivkins kinematics module using repeated coordinate letters. For example, a machine configured with ini settings:

```
[KINS]
KINEMATICS = trivkins coordinates=XYZ kinstype=BOTH
...
[TRAJ]
COORDINATES = XYZ
...
```

This machine, after homing, has a one-to-one correspondence between a single axis letter (Y) and a pair of joints (1,2). Using *kinematics=BOTH* allows control of individual joints in joint mode *if/when required*.

4.7.3.3 Non-identity kinematics

The axis gui supports configurations using non-identity kinematics with:

1. Key binding (\$) to toggle joint or teleop mode
2. Preview Tab display of joints or axes according to joint or teleop mode
3. Preview Tab display of *Home* and *Limit* icons in joint mode
4. Preview Tab display of *All-homed* and *Any-limit* icons in teleop mode
5. DRO Tab display of joint or axes according to joint or teleop mode
6. Jogging is supported in both joint and teleop motion modes
7. External changes to the joint/teleop motion mode are detected.

4.7.3.4 Home icons

For identity kinematics, *Home* icons are shown for the corresponding (one-to-one) axis letter when a joint is homed.

For non-identity kinematics, *Home* icons are shown for individual joints when a joint is homed in joint display mode. An *All-homed* icon is displayed for all axis letters when ALL joints are homed in world display mode.

4.7.3.5 Limit icons

For identity kinematics, *Limit* icons are shown for the corresponding (one-to-one) axis letter when a joint limit is active.

For non-identity kinematics, *Limit* icons are shown for individual joints when the joint limit is active in joint display mode. An *Any-Limit* icon is displayed if any joint is at a limit in teleop display mode.

4.7.3.6 Key bindings for a fourth axis

In the AXIS gui, jogging keys are assigned to axes in a configurable fashion. For 3-axis machines, XYZA machines, and lathes the default is the same as in 2.7. For other machines, the 4 pairs of jogging keys are assigned to the first 4 axes that exist in the order XYZ ABC UVW. These assignments can be controlled by new inifile directives in the [\[DISPLAY\] section of the inifile](#)

Note that the parameters used for jogging may not be appropriate for both modes for machines with non-identity kinematics.

4.7.4 tklinuxcnc

The tklinuxcnc gui supports both identity and non-identity kinematics, includes gui radiobuttons and a key binding (\$) for toggling joint and teleop modes. External changes to joint or teleop motion mode are detected. Jogging is supported in both joint and teleop motion modes. Note that the parameters used for jogging may not be appropriate for both modes for machines with non-identity kinematics.

OpenGL is not used by tklinuxcnc so it may be used to isolate problems and system dependencies that are exposed with more modern guis like axis.

The rudimentary backplot gui provided is available for use with identity kinematics (xyz) machine configurations.

4.7.4.1 emcsh commands

The code of `emcsh.cc` provides the set of tcl commands used by `tklinuxcnc`. The commands are available to tcl applications as the tcl package named *Linuxcnc*. A number of commands previously required the use of a numeric argument to specify an axis coordinate (0-->X, 1-->Y, ..., 8-->W). These commands have been simplified to use an argument that is just the coordinate letter.

Commands now using a coordinate letter argument are:

1. `emc_pos_offset`
2. `emc_abs_cmd_pos`
3. `emc_abs_act_pos`
4. `emc_rel_cmd_pos`
5. `emc_rel_act_pos`
6. `emc_tool_offset`
7. `emc_probed_pos`

4.7.5 touchy

The `touchy` gui continues to support the identity kinematics configurations that it supported prior to `joints_axes` incorporation. Jogging is done in teleop mode.

4.7.6 gscreen

The `gscreen` gui continues to support the identity kinematics configurations that it supported prior to `joints_axes` incorporation. Jogging is done in teleop mode.

4.7.7 gmoccapy

The `gmoccapy` gui continues to support the identity kinematics configurations that it supported prior to `joints_axes` incorporation. Jogging is done in teleop mode.

4.7.8 shuttleexpress driver renamed to shuttle

The HAL driver for the Contour Designs ShuttleXpress device has been renamed from "shuttleexpress" to just "shuttle". If your hal files include some variant of "loadusr shuttleexpress", replace "shuttleexpress" with "shuttle".

Support has been added for the ShuttlePRO, a bigger version of the ShuttleXpress, so the old driver name is no longer accurate.

4.7.9 linuxcncrsh

"Home All" is now supported with the `set home` subcommand by using -1 for the joint number

The jogging commands have been altered to accomodate both joint (free) and teleop (world) jogging.

```
was: set jog      joint_number      speed
is: set jog      joint_number|axis_letter speed

was: set jog_incr joint_number      speed increment
is: set jog_incr joint_number|axis_letter speed increment

was: set jog_stop
is: set jog_stop joint_number|axis_letter
```

Note: Test for teleop mode using command: `get teleop_enable` if `TELEOP_ENABLE=YES`, use `axis_letter` else use `joint_number`

Note: Formerly, the command `set jog 0 1.234` would jog the zeroth axis (X) with requested speed=1.234 in any mode (free or teleop). This command now attempts to jog the zeroth joint (Joint0) provided the mode is free (not teleop). To jog the X axis, the mode must be teleop and the corresponding command is: `set jog x 1.234`

4.8 Tools

4.8.1 Calibration (emccalib.tcl)

The calibration/tuning tool now supports stanzas:

```
[JOINT_N], [AXIS_L], [SPINDLE_S], [TUNE]
```

where N is a joint number (0 .. ([KINS]JOINTS-1)), L is an axis coordinate letter (X,Y,Z,A,B,C,U,V,W), and S is a spindle number (0 .. 9)

Note

The number of allowed spindles is 8 but legacy configurations may include a stanza `[SPINDLE_9]` unrelated to an actual spindle number.

Note

The `[TUNE]` stanza may be used for specifying tunable items not relevant to the other supported stanzas.

4.9 Obsolete Guis (removed for 2.8.x)

The guis *mini*, *keystick*, and *xlinuxcnc* have been removed in conjunction with updates for `joints_axes`. All related source code, examples, and documentation are available in the git repository.

4.10 Deprecated Guis (marked at 2.8.x)

The *linuxcncld* gui is a candidate for removal. Should this component be removed, all related source code, examples, and documentation will be available in the git repository.

4.11 Simulator configurations (updates for joints axes 2.8.x)

4.11.1 Pre-joints_axes

Prior to `joints_axes` incorporation, the halfiles used in sim configs typically supported a common milling machine — a Cartesian system with trivial kinematics and three axes named *X Y Z*. Typical halfile entries:

```
[HAL]
HALFILE = core_sim.hal
HALFILE = sim_spindle_encoder.hal
HALFILE = axis_manualtoolchange.hal
HALFILE = simulated_home.hal
```

Lathe configs often shared the same halfiles and used the expedient method of specifying 3 axes with *Y* unused. More complex sim configs provided specific sets of halfiles according to the configuration purpose.

4.11.2 Post-joints_axes

With the incorporation of joints_axes functionality, many sims provided in the distribution now take advantage of a general purpose halfile that supports numerous configurations automatically. A typical sim config HALFILE specification is:

```
[HAL]
HALFILE = LIB:basic_sim.tcl
```

The basic_sim.tcl HALFILE supports a number of commonly required functions for any number of joints as specified by:

```
[KINS]
...
JOINTS = number_of_joints
...
```

Functions supported include:

1. *ddts* — differentiator hal components are loaded and connected for each joint (and xy, xyz for trivkins machines)
2. *simulated_home* — a sim_home_switch hal component is loaded and connected for each joint. The homing conditions are specified by the usual [JOINT_n]HOME_* ini file items.
3. *use_hal_manualtoolchange* — the user space hal_manualtoolchange component is loaded and connected.
4. *sim_spindle* — the sim_spindle component is loaded and connected to additional loaded hal components to simulate the inertia of a rotating spindle mass.

The functions are activated by default but can be excluded using options: *-no_make_ddts*, *-no_simulated_home*, *-no_use_hal_manualtoolchange*, *-no_sim_spindle*.

For example, to omit creation of ddts:

```
HALFILE = LIB:basic_sim.tcl -no_make_ddts
```

Omitting one or more of the core functions allows testing without the function or addition of new HALFILES to implement or expand on the functionality.

4.11.2.1 Equivalent Hal commands file

When LIB:basic_sim.tcl is used, an equivalent halfile is created (in the configuration directory) to show the halcmd commands issued. The file name is based on the name of the inifile with *_cmds* appended to the basename and a conventional *.hal* file extension. Example:

```
inifilename:          example.ini
equivalent_halfilename: example_cmds.hal
```

The equivalent halfile file supersedes previous instances of files with the same filename. Inifile variables substitutions specified in the inifile and interpreted by halcmd are automatically substituted in the created halfile. If there are [HAL]HALFILES specified before LIB:basic_sim.tcl, their halcmd commands are included too.

The equivalent halfile can be used to create a new configuration based on the original configuration made with LIB:basic_sim.tcl with the following steps:

- 1) Run the simulator configuration to create a new equivalent halfile, for example: *example_cmds.hal*.

To use this new equivalent halfile in the original simulator configuration inifile (or a copy of it), edit to change:

```
[HAL]
HALFILE = LIB:basic_sim.tcl other_parameters
```

to:

```
[HAL]
HALFILE = ./example_cmds.hal
```

4.11.2.2 Notes

All components and connections made by LIB:basic_sim.tcl can be viewed using halcmd. The entire hal configuration (except for userspace components loaded with loadusr) can be saved to a file using:

```
$ halcmd save > hal.save
```

Use of LIB:basic_sim.tcl reduces the effort needed to make a simulation config since it handles most of the required component loading and hal connections.

The sim config *Sample Configurations/sim/axis/minimal_xyz.ini* demonstrates a working xyz configuration that uses LIB:basic_sim.tcl with a minimal number of ini file settings.

4.12 Miscellaneous updates for 2.8.x

Commits to unreleased branches may make changes that affect testers and early-adopters of the unreleased software.

4.12.1 Motion pins

New pins (see the motion man page for more info):

```
--- axis.L.jog-accel-fraction joint.N.jog-accel-fraction ---
```

4.12.2 Hal pins

Name changes:

```
was: axis.L.vel-cmd
is: axis.l.teleop-vel-cmd
```

New pins:

```
motion.homing-inhibit (see motion manpage)
```

4.12.3 Hal component updates

1. siggen: new pin *reset* to set output signal values to predefined state
2. biquad: pins *type*, *f0*, *Q*, *s1*, *s2* were formerly params
3. userkins: template for user-built kinematics modules using halcompile

4.12.4 XHC-HB04 Pendant Support

4.12.4.1 xhc_hb04_util.comp (helper component)

Remove unused pin *jogenable-off*

Add pin *amux-enable* so that the multiplexed acceleration reductions are now enabled by the ANDing the pins: *is-manual* and *amux-enable*. These two pins are typically connected to *halui.mode.is-manual* and *halui.mode.is-teleop* respectively.

4.12.4.2 xhc_hb04.tcl (optional LIB configuration halfile)

Remove signal pendant:jogenable-off for removed pin *pendant_util.jogenable-off*

Support new motion pins for reduced accelerations (axis.L.jog-accel-fraction, joint.N.jog-accel-fraction) for wheel jogging. The use of [APPLICATIONS]APP=xhc-hb04-accel is no longer supported. Reduced accels are applied for wheel jogging only (not for nml commands issued by guis).

4.12.5 XHC-WHB04B-6 pendant support

See the documentation for the xhc-whb04b-6 component.

4.12.6 bldc3_hall

The bldc_hall3 component has been removed. The **bldc** component is more flexible and better tested.

4.12.7 [JOINT_n]HOME_SEQUENCE Starting values

Starting sequence values may be 0, 1 (or -1) only. See the "Homing Configuration" documentation for more information.

4.12.8 [JOINT_n]HOME_SEQUENCE Negative values

Joints using a negative HOME_SEQUENCE are not allowed to jog in joint mode in order to prevent misalignment (racking) in common gantry configurations. As always, machines with any kinematics type must be homed prior to enabling conventional world mode jogging.

4.12.9 TWOPASS support for complex loadrt config= items

Added twopass support for loadrt config modparams with multiple settings separated by blanks and enclosed with quotes. Example:

```
loadrt hm2_eth board_ip=10.10.10.10 config="num_encoders=2 num_pwmgens=2 num_stepgens=3"
```

4.13 Changes beyond 2.8.x

Future versions of this document will note changes made to the development branch subsequent to 2.8.x release(s).

Chapter 5

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 controlled with hardware. Gmoccapy is highly customizable.

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 a 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 6

Legal Section

6.1 Copyright Terms

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