Lane Following RC Vehicle

Using Embedded ROS on Petalinux

Nathan Kelley
Andrew Dejonge

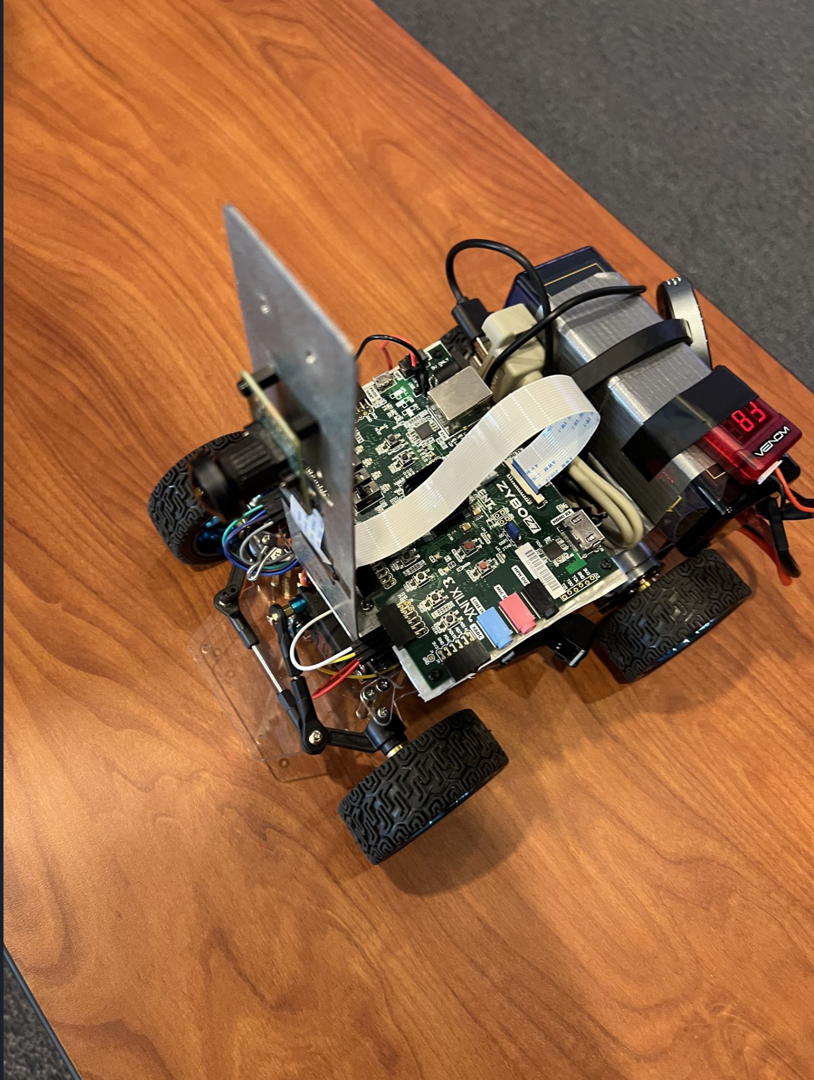
Mike Bowers: Hardware/Physical

Intro

Hybrid Autonomous Vehicle

- Takes in a video stream
- Follows a Lane
- Recognizes Basic Signs

- Hardware: VHDL on FPGA
- Software: ROS on Zynq, using Petalinux



Itinerary

Brief High Level Description:

- Physical System
- Hardware / VHDL Definition

—----------------

Initialization:

- Installing Petalinux
- Building Petalinux
- Getting Dependencies
- ANDREW FIX THIS

—--------------------

Implementation:

- PID Control
- AXI Memory Read/Writes

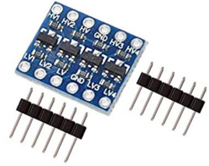
—--------------------

System Performance & Limits

Demo

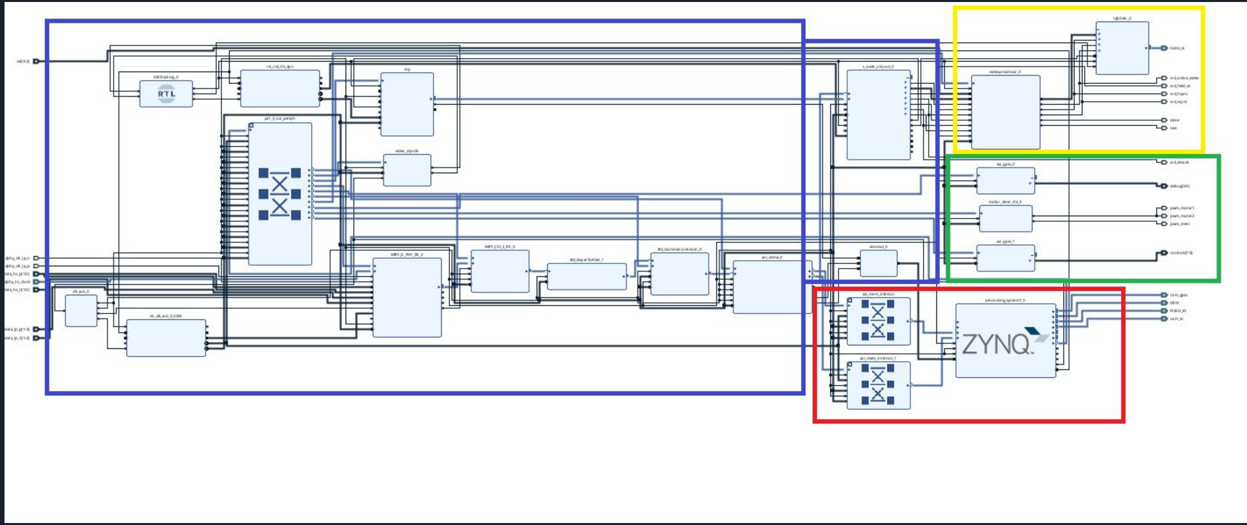
Physical System Definition

- Osoyoo Servo Steering Robot Smart Car
- POVWAY 11V RC CAR Li Battery
- PCAM5 - 720p60fps camera
- MGR996R Servo Motor (Steering)
- JGA25 DC Drive Motors
- Zybo z720 dev board
- Level Shifters/Hbridges



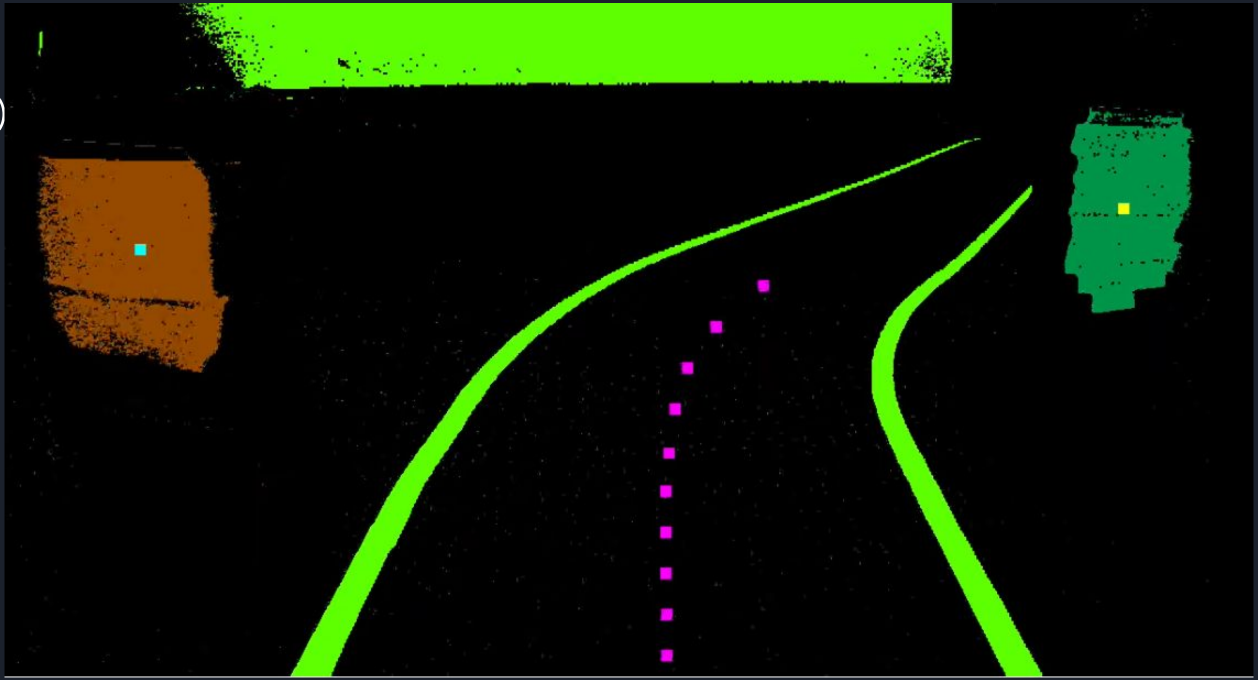
Hardware Definition

- Blue: HDMI Interface
- Yellow: Video Processor
- Green: PWM Motor Ctrl
- Red: Zynq Processing System

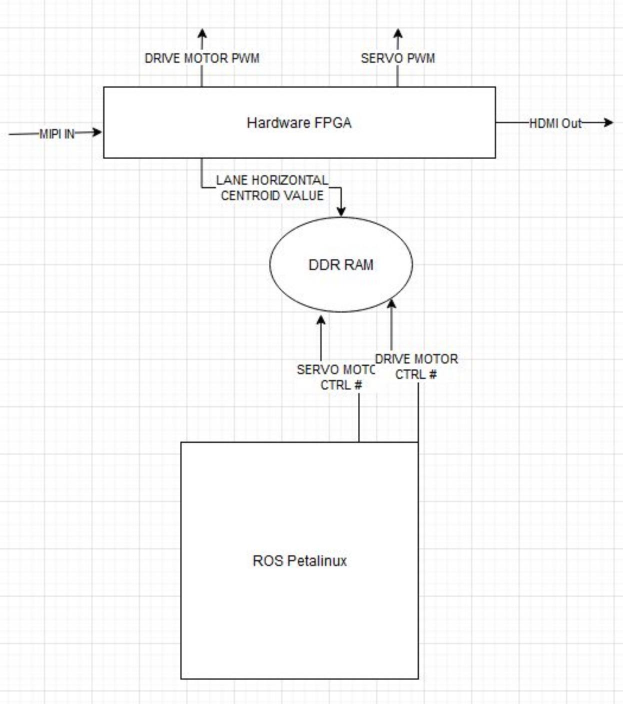


Hardware Functionality

- Detects L/R lane lines
- Avgs them (Pink Dots)
- Writes to DDR RAM
- Outputs to Screen



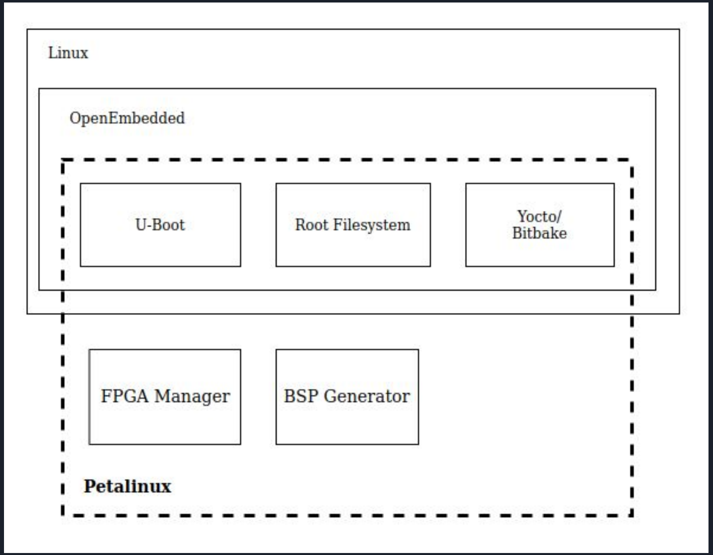
Hardware Definition: Black-Box



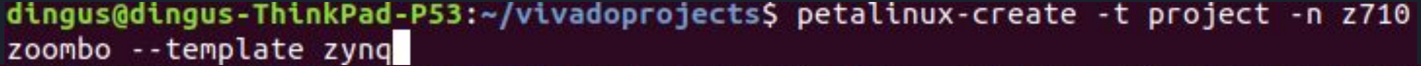
Petalinux and Robot Operating System

What is Petalinux?

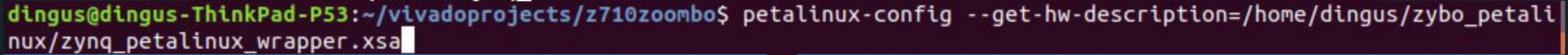
- Xilinx’s version of OpenEmbedded tools
- Specialized for Zynq-7000/Ultrascale, Microblaze, Versal
- Generates both a Linux build and an FPGA design description
- Automates some of the Yocto tools for building
  - Provides a set of predefined layers
  - Runs bitbake commands based on chosen layers
- Provides simple GUI for build configuration



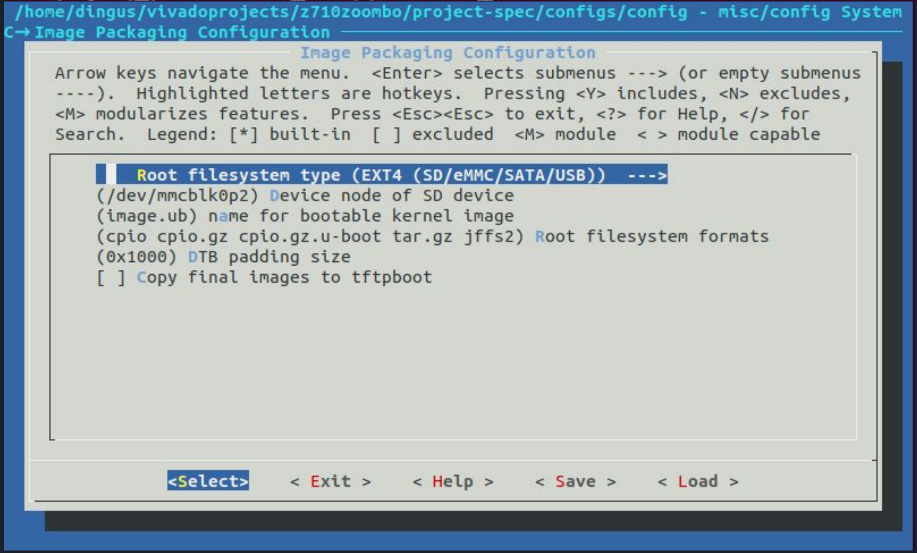
Building with Petalinux



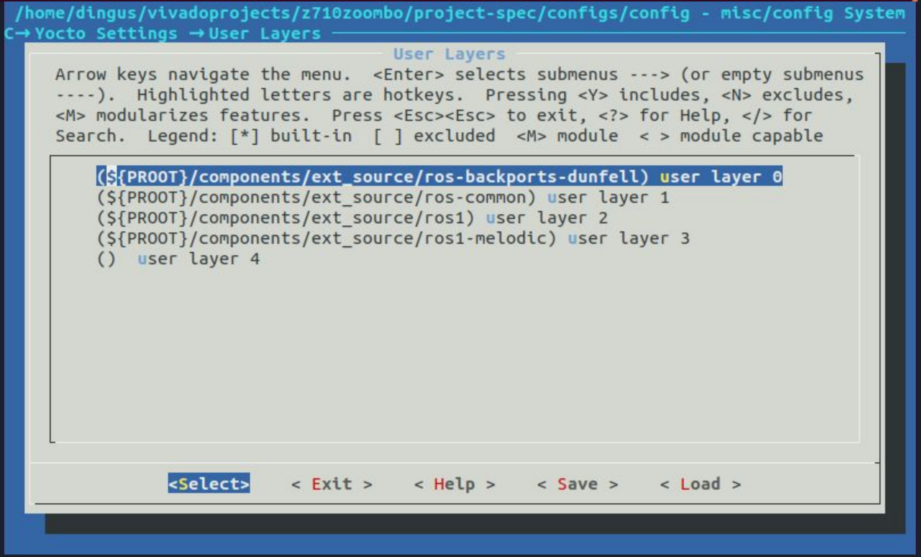
```
dingus@dingus-ThinkPad-P53:~/vivadoprojects$ petalinux-create -t project -n z710
zoombo --template zynq
```



```
dingus@dingus-ThinkPad-P53:~/vivadoprojects/z710zoombo$ petalinux-config --get-hw-description=/home/dingus/zybo_petali
nux/zynq_petalinux_wrapper.xsa
```

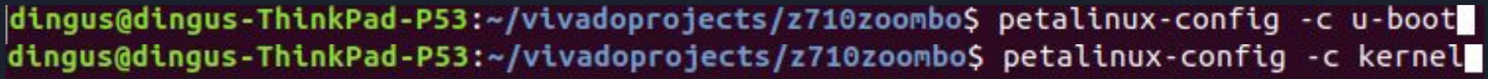


```
 /home/dingus/vivadoprojects/z710zoombo/project-spec/configs/config - misc/config System
C→ Image Packaging Configuration
                    Image Packaging Configuration
  Arrow keys navigate the menu.  <Enter> selects submenus ---> (or empty submenus
  ----).  Highlighted letters are hotkeys.  Pressing <Y> includes, <N> excludes,
  <M> modularizes features.  Press <Esc><Esc> to exit, <?> for Help, </> for
  Search.  Legend: [*] built-in  [ ] excluded  <M> module  < > module capable

      Root filesystem type (EXT4 (SD/eMMC/SATA/USB))  --->
      (/dev/mmcblk0p2) Device node of SD device
      (image.ub) name for bootable kernel image
      (cpio cpio.gz cpio.gz.u-boot tar.gz jffs2) Root filesystem formats
      (0x1000) DTB padding size
      [ ] Copy final images to tftpboot

          <Select>    < Exit >    < Help >    < Save >    < Load >
```

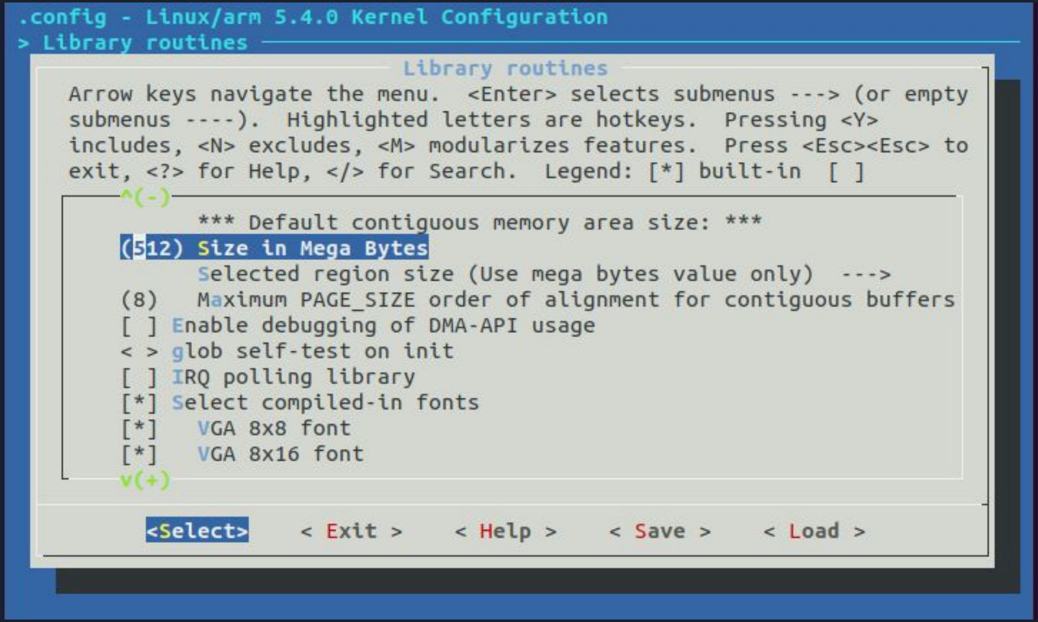


```
 /home/dingus/vivadoprojects/z710zoombo/project-spec/configs/config - misc/config System
C→ Yocto Settings → User Layers
                              User Layers
  Arrow keys navigate the menu.  <Enter> selects submenus ---> (or empty submenus
  ----).  Highlighted letters are hotkeys.  Pressing <Y> includes, <N> excludes,
  <M> modularizes features.  Press <Esc><Esc> to exit, <?> for Help, </> for
  Search.  Legend: [*] built-in  [ ] excluded  <M> module  < > module capable

      (${PROOT}/components/ext_source/ros-backports-dunfell) user layer 0
      (${PROOT}/components/ext_source/ros-common) user layer 1
      (${PROOT}/components/ext_source/ros1) user layer 2
      (${PROOT}/components/ext_source/ros1-melodic) user layer 3
      ()  user layer 4

          <Select>    < Exit >    < Help >    < Save >    < Load >
```

Building with Petalinux

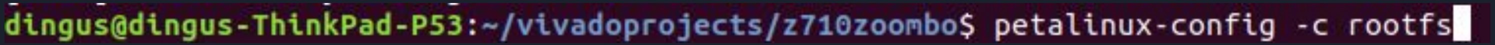


```
dingus@dingus-ThinkPad-P53:~/vivadoprojects/z710zoombo$ petalinux-config -c u-boot
dingus@dingus-ThinkPad-P53:~/vivadoprojects/z710zoombo$ petalinux-config -c kernel
```

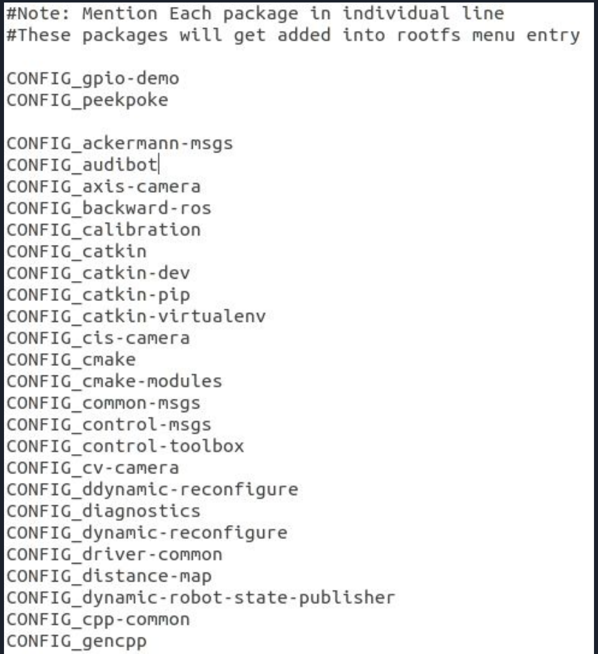


```
.config - Linux/arm 5.4.0 Kernel Configuration
> Library routines
                              Library routines
  Arrow keys navigate the menu.  <Enter> selects submenus ---> (or empty
  submenus ----).  Highlighted letters are hotkeys.  Pressing <Y>
  includes, <N> excludes, <M> modularizes features.  Press <Esc><Esc> to
  exit, <?> for Help, </> for Search.  Legend: [*] built-in  [ ]
      ^(-)
            *** Default contiguous memory area size: ***
      (512) Size in Mega Bytes
            Selected region size (Use mega bytes value only)  --->
      (8)   Maximum PAGE_SIZE order of alignment for contiguous buffers
      [ ] Enable debugging of DMA-API usage
      < > glob self-test on init
      [ ] IRQ polling library
      [*] Select compiled-in fonts
      [*]   VGA 8x8 font
      [*]   VGA 8x16 font
      v(+)

        <Select>    < Exit >    < Help >    < Save >    < Load >
```

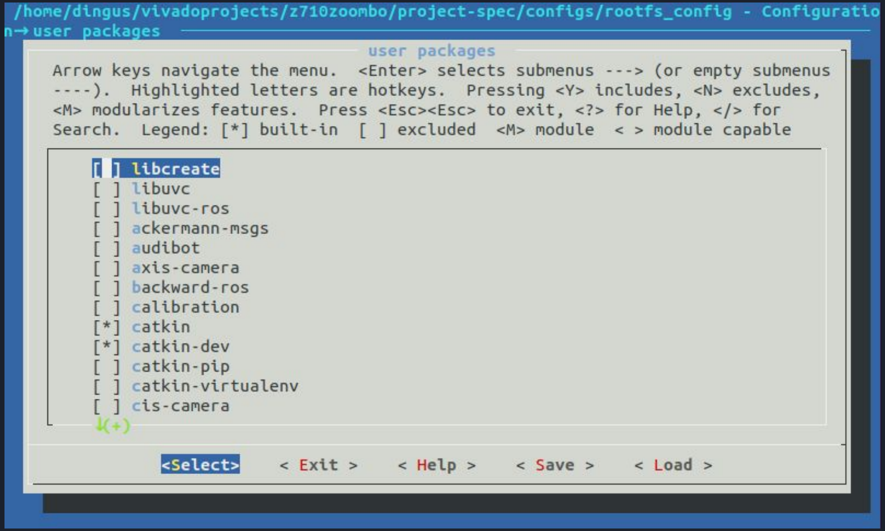
Building with Petalinux



```
dingus@dingus-ThinkPad-P53:~/vivadoprojects/z710zoombo$ petalinux-config -c rootfs
```

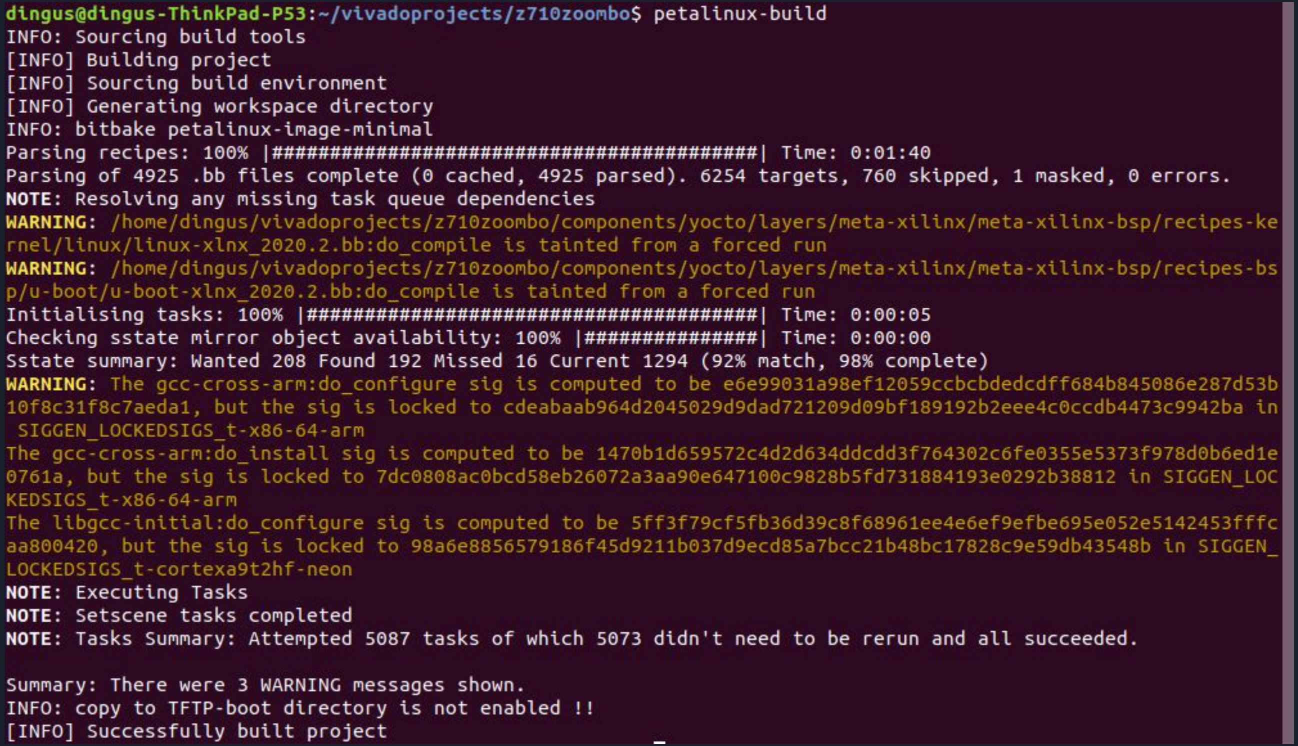


```
#Note: Mention Each package in individual line
#These packages will get added into rootfs menu entry

CONFIG_gpio-demo
CONFIG_peekpoke

CONFIG_ackermann-msgs
CONFIG_audibot
CONFIG_axis-camera
CONFIG_backward-ros
CONFIG_calibration
CONFIG_catkin
CONFIG_catkin-dev
CONFIG_catkin-pip
CONFIG_catkin-virtualenv
CONFIG_cis-camera
CONFIG_cmake
CONFIG_cmake-modules
CONFIG_common-msgs
CONFIG_control-msgs
CONFIG_control-toolbox
CONFIG_cv-camera
CONFIG_ddynamic-reconfigure
CONFIG_diagnostics
CONFIG_dynamic-reconfigure
CONFIG_driver-common
CONFIG_distance-map
CONFIG_dynamic-robot-state-publisher
CONFIG_cpp-common
CONFIG_gencpp
```



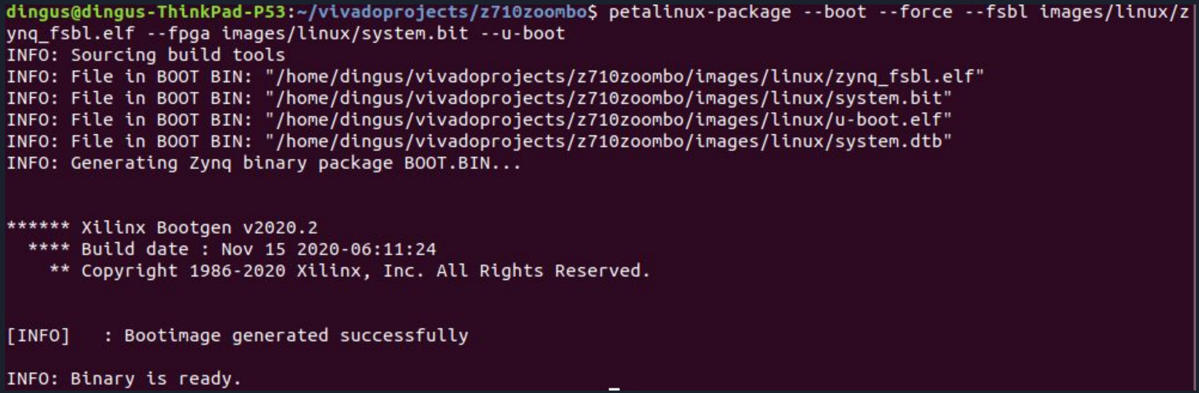
```
/home/dingus/vivadoprojects/z710zoombo/project-spec/configs/rootfs_config - Configuratio
n→ user packages ──────────────────────────────────────────────────────────────
                                  user packages
  Arrow keys navigate the menu.  <Enter> selects submenus ---> (or empty submenus
  ----).  Highlighted letters are hotkeys.  Pressing <Y> includes, <N> excludes,
  <M> modularizes features.  Press <Esc><Esc> to exit, <?> for Help, </> for
  Search.  Legend: [*] built-in  [ ] excluded  <M> module  < > module capable

        [ ] libcreate
        [ ] libuvc
        [ ] libuvc-ros
        [ ] ackermann-msgs
        [ ] audibot
        [ ] axis-camera
        [ ] backward-ros
        [ ] calibration
        [*] catkin
        [*] catkin-dev
        [ ] catkin-pip
        [ ] catkin-virtualenv
        [ ] cis-camera
        ↓(+)

          <Select>    < Exit >    < Help >    < Save >    < Load >
```

Building with Petalinux

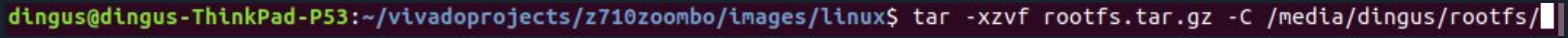


```
dingus@dingus-ThinkPad-P53:~/vivadoprojects/z710zoombo$ petalinux-build
INFO: Sourcing build tools
[INFO] Building project
[INFO] Sourcing build environment
[INFO] Generating workspace directory
INFO: bitbake petalinux-image-minimal
Parsing recipes: 100% |##########################################| Time: 0:01:40
Parsing of 4925 .bb files complete (0 cached, 4925 parsed). 6254 targets, 760 skipped, 1 masked, 0 errors.
NOTE: Resolving any missing task queue dependencies
WARNING: /home/dingus/vivadoprojects/z710zoombo/components/yocto/layers/meta-xilinx/meta-xilinx-bsp/recipes-ke
rnel/linux/linux-xlnx_2020.2.bb:do_compile is tainted from a forced run
WARNING: /home/dingus/vivadoprojects/z710zoombo/components/yocto/layers/meta-xilinx/meta-xilinx-bsp/recipes-bs
p/u-boot/u-boot-xlnx_2020.2.bb:do_compile is tainted from a forced run
Initialising tasks: 100% |#######################################| Time: 0:00:05
Checking sstate mirror object availability: 100% |###############| Time: 0:00:00
Sstate summary: Wanted 208 Found 192 Missed 16 Current 1294 (92% match, 98% complete)
WARNING: The gcc-cross-arm:do_configure sig is computed to be e6e99031a98ef12059ccbcbdedcdff684b845086e287d53b
10f8c31f8c7aeda1, but the sig is locked to cdeabaab964d2045029d9dad721209d09bf189192b2eee4c0ccdb4473c9942ba in
 SIGGEN_LOCKEDSIGS_t-x86-64-arm
The gcc-cross-arm:do_install sig is computed to be 1470b1d659572c4d2d634ddcdd3f764302c6fe0355e5373f978d0b6ed1e
0761a, but the sig is locked to 7dc0808ac0bcd58eb26072a3aa90e647100c9828b5fd731884193e0292b38812 in SIGGEN_LOC
KEDSIGS_t-x86-64-arm
The libgcc-initial:do_configure sig is computed to be 5ff3f79cf5fb36d39c8f68961ee4e6ef9efbe695e052e5142453fffc
aa800420, but the sig is locked to 98a6e8856579186f45d9211b037d9ecd85a7bcc21b48bc17828c9e59db43548b in SIGGEN_
LOCKEDSIGS_t-cortexa9t2hf-neon
NOTE: Executing Tasks
NOTE: Setscene tasks completed
NOTE: Tasks Summary: Attempted 5087 tasks of which 5073 didn't need to be rerun and all succeeded.

Summary: There were 3 WARNING messages shown.
INFO: copy to TFTP-boot directory is not enabled !!
[INFO] Successfully built project
```

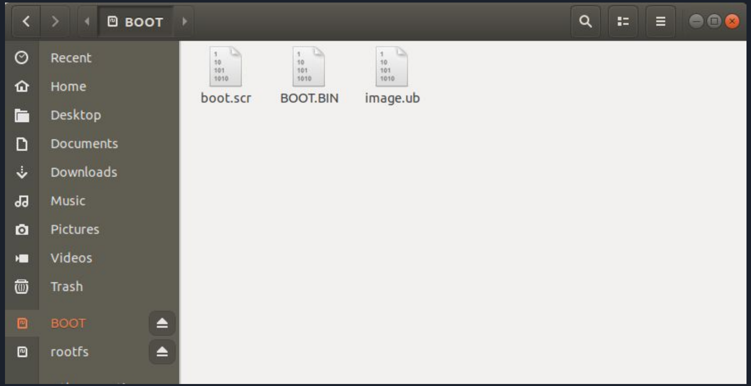
Building with Petalinux

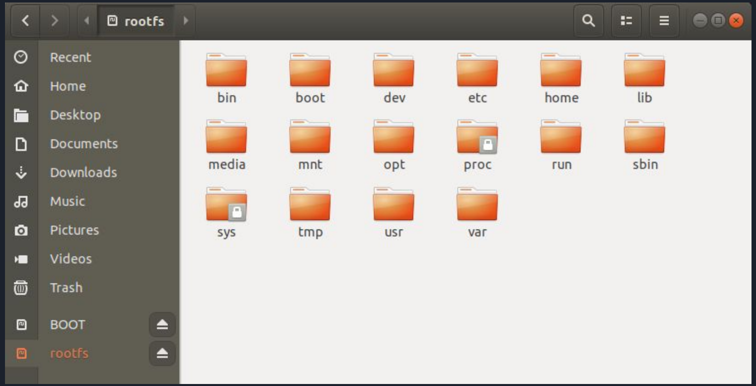


```
dingus@dingus-ThinkPad-P53:~/vivadoprojects/z710zoombo$ petalinux-package --boot --force --fsbl images/linux/z
ynq_fsbl.elf --fpga images/linux/system.bit --u-boot
INFO: Sourcing build tools
INFO: File in BOOT BIN: "/home/dingus/vivadoprojects/z710zoombo/images/linux/zynq_fsbl.elf"
INFO: File in BOOT BIN: "/home/dingus/vivadoprojects/z710zoombo/images/linux/system.bit"
INFO: File in BOOT BIN: "/home/dingus/vivadoprojects/z710zoombo/images/linux/u-boot.elf"
INFO: File in BOOT BIN: "/home/dingus/vivadoprojects/z710zoombo/images/linux/system.dtb"
INFO: Generating Zynq binary package BOOT.BIN...


****** Xilinx Bootgen v2020.2
  **** Build date : Nov 15 2020-06:11:24
    ** Copyright 1986-2020 Xilinx, Inc. All Rights Reserved.


[INFO]   : Bootimage generated successfully

INFO: Binary is ready.
```



```
dingus@dingus-ThinkPad-P53:~/vivadoprojects/z710zoombo/images/linux$ tar -xzvf rootfs.tar.gz -C /media/dingus/rootfs/
```





How to run ROS code on Petalinux?

Two Options:

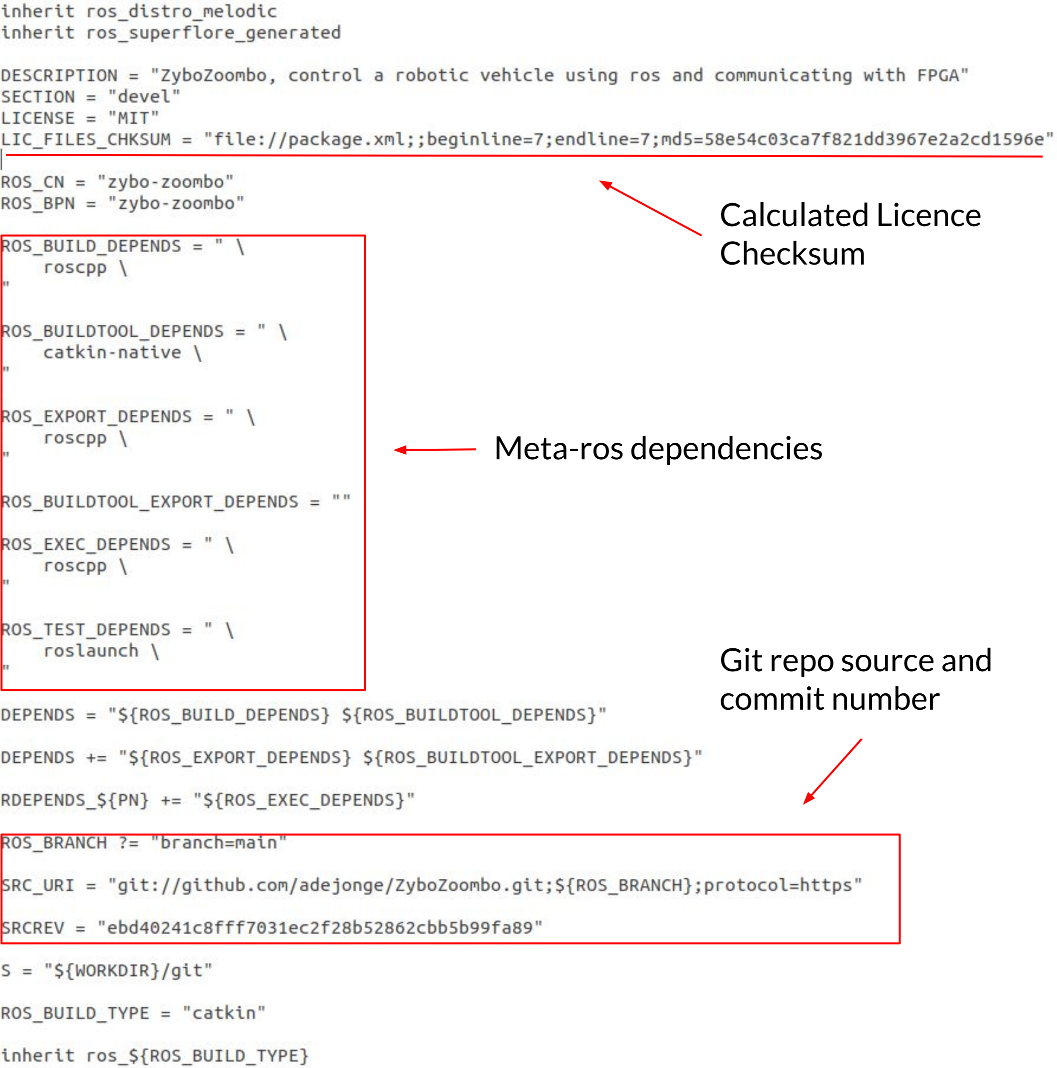
Compile on Embedded Device

- Need to add a C/C++ compiler to build, as well as ROS build tools
- Need git added to build, then pull code from repo onto device
- Too difficult to add all necessary layers and dependencies without running out of resources

Add to Linux Build

- Need to create recipe for ROS project
- Recipe needs to be updated anytime git repo is updated
- Still need some dependencies added into Petalinux build
- Chosen as the better path

Bitbake Recipe



```
inherit ros_distro_melodic
inherit ros_superflore_generated

DESCRIPTION = "ZyboZoombo, control a robotic vehicle using ros and communicating with FPGA"
SECTION = "devel"
LICENSE = "MIT"
LIC_FILES_CHKSUM = "file://package.xml;;beginline=7;endline=7;md5=58e54c03ca7f821dd3967e2a2cd1596e"

ROS_CN = "zybo-zoombo"
ROS_BPN = "zybo-zoombo"

ROS_BUILD_DEPENDS = " \
    roscpp \
"

ROS_BUILDTOOL_DEPENDS = " \
    catkin-native \
"

ROS_EXPORT_DEPENDS = " \
    roscpp \
"

ROS_BUILDTOOL_EXPORT_DEPENDS = ""

ROS_EXEC_DEPENDS = " \
    roscpp \
"

ROS_TEST_DEPENDS = " \
    roslaunch \
"

DEPENDS = "${ROS_BUILD_DEPENDS} ${ROS_BUILDTOOL_DEPENDS}"

DEPENDS += "${ROS_EXPORT_DEPENDS} ${ROS_BUILDTOOL_EXPORT_DEPENDS}"

RDEPENDS_${PN} += "${ROS_EXEC_DEPENDS}"

ROS_BRANCH ?= "branch=main"

SRC_URI = "git://github.com/adejonge/ZyboZoombo.git;${ROS_BRANCH};protocol=https"

SRCREV = "ebd40241c8fff7031ec2f28b52862cbb5b99fa89"

S = "${WORKDIR}/git"

ROS_BUILD_TYPE = "catkin"

inherit ros_${ROS_BUILD_TYPE}
```

Calculated Licence Checksum

Meta-ros dependencies

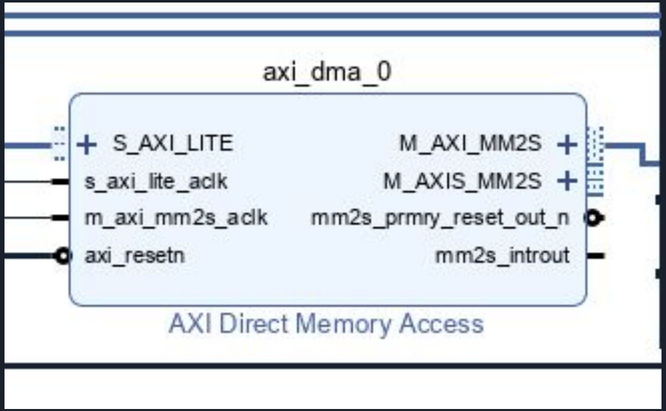
Git repo source and commit number

READS: Memory → Motors

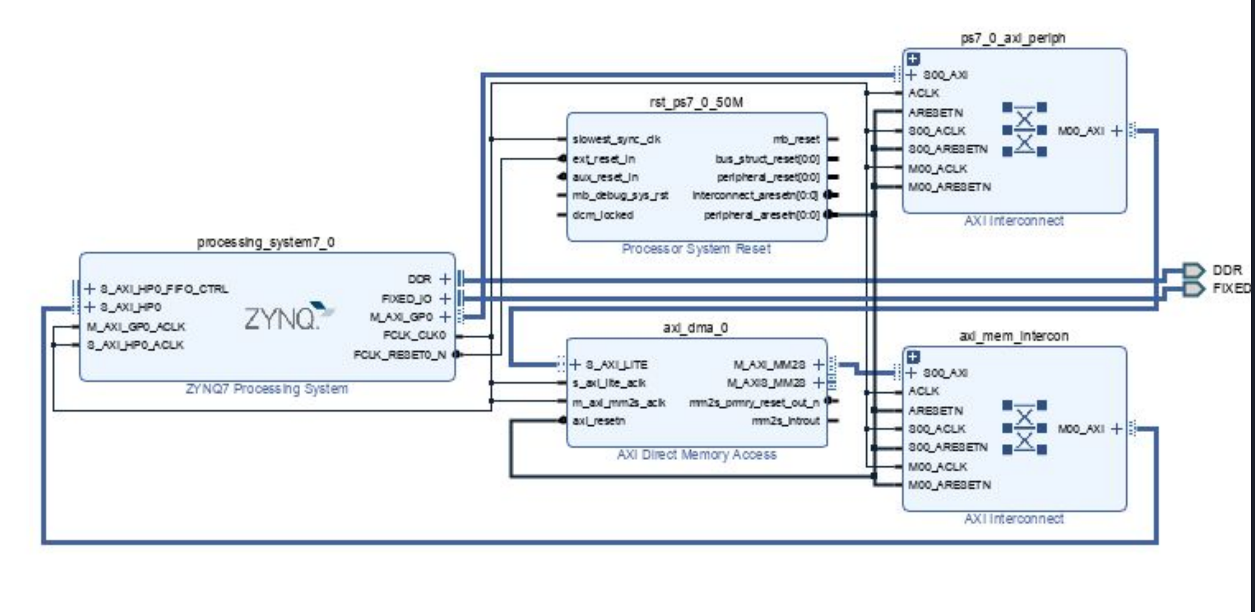
- Command # : 0 -> 200
- Stored in shared DRAM

READ Command # from Memory

WRITE : hcount of lane centroid.



WRITES: Video Controller → ROS DRAM



System Limits:

Response Time on frame (1/60) = 16.7ms
3 frame pipeline
Fastest Response Time (60Hz) = 41.6ms;

Driver Total Reaction Time = 1.5s
AVS Safety System response requirement = 500ms
AVS Safety System Avg response time = 200 - 300ms
AVS new Safety System tech = 19ms;

Demo

https://www.youtube.com/shorts/f_cf0l6KRUU

References

- Running Petalinux on Zynq SoC From Scratch - Zybo Board
- ROS 2 in Kria kv260 with Petalinux 2021.2
- Meta-ros OpenEmbedded Build Instructions
- Adding GCC to PetaLinux builds (compiling code on FPGA PS)
- How to boot petalinux image with >1.5 GB root file system on both petalinux-qemu and sd card on zcu104 board
- PetaLinux Tools Documentation
- Create a bitbake recipe for a ROS package and cross-compile it using the meta-ros project