Computer Vision

In FRC Robot Designs

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Specifications

Goals

Develop a software/hardware sub-system that can be used for computer vision based auto-targeting and FRC field element recognition

Requirements

1. Solution needs to operate in real time on real hardware
2. Solution needs to be supported in simulation as well as real hardware
3. Solution must at least offer basic image processing libraries
4. Solution needs to be low cost

Desirable Features

1. Can segment objects (“particles”,”ROIs”) from images (using filters, moment analysis etc.)
2. Can identify specific objects in images (e.g. target tape pattern, totes etc.)
3. Object identification accuracy can be improved by training
4. Offers Multi-Processor Support (multi-core cpus, GPUs)

Available Software packages and APIs

1. CUDA (Compute Unified Device Architecture**)**
   - C++ API that includes compiler directives that support multi-processing
   - Only supported on NVIDIA hardware (graphics boards)
2. cuDNN (NVIDIA Deep Neural Network Library)

- Provides high level API for “deep learning” programming
- Uses CUDA compute engine as back end
- Only supported on NVIDIA hardware

3. Caffe (Deep learning Framework)
    - Developed by the Berkley Learning and Vision Center
    - Provides Python or Matlab API shells to CUDA(GPU) or OpenCL(CPU only) compute engines
    - Caffe-cuDNN requires top-end NVIDIA hardware for training
    - Trained networks can be deployed on lower-end NVIDIA hardware (e.g. Jetson)
4. Digits (graphical interface for deep learning)
    - Requires top-end NVIDIA hardware and software
    - Trained networks can be deployed on lower level hardware (e.g. Jetson)
    - Supports “deep learning” algorithms (Neural networks)
5. OpenCL (Open Computing Language)
    - Open source alternative to CUDA
    - Runs on most hardware platforms (AMD,NVIDIA,INTEL)
6. OpenCV (Open Computer Vision)
    - Runs on most os platforms (Linux, OSX, Windows, Arm)
    - Supports image filtering
    - May also support object identification and training (need to investigate)
7. IMAQ (ni-vision)
    - National Instruments proprietary software (commercial)
    - Only supported on RoboRio hardware
    - No possibility of simulation support
    - Supports object segmentation only (no object classification or training)
8. GRIP
    - Recently adopted by First as an alternate image processing package (over ni-vision)

- Uses OpenCV image processing background engine
- Uses JavaFX for front end UI
- Can be built from source on Windows and Linux (Mac?)
- Has GUI tuning application and headless implementation for deployment

Target Hardware platforms

1. Multicore x86_64 CPU
2. Raspberry Pi-3
3. Jetson TK1 (TX1)
4. RoboRio

Strategies

Image processing Strategies

Use a relatively simple image processing API (e.g. GRIP, IMAQ)

- The image processing system uses filters, color match algorithms etc. to isolate portions of a camera image that meet certain criteria for special target objects (reflective tape patterns etc.)
- The image processing system performs an analysis on these regions of interest (ROIs) and extracts basic information such as length,width (in pixels) position of object center on the screen etc.
- The reduced ROI data is sent from the image processing system to the Robot application
- The Robot application uses the ROIs center point width, height etc. along with prior knowledge of the objects size and shape to determine both the distance of the object from the camera and it's horizontal and vertical offset angles
- The Robot application uses the geometric data obtained for the target to adjust it's heading, shooter angle etc. as appropriate

Use an advanced object recognition API (e.g. cuDNN, Caffe, DIGITS)

- ○ Similar to that described above except that a more advanced technique (e.g. “Deep learning”) is used to identify objects based on general training data rather than relying on a set of unique target image properties (that may not be available in all situations)
- ○ Using such advanced techniques might require a more capable compute resource such as a

NVIDIA Jetson graphics card

Deployment Strategies

Use a single processor for both image processing and Robot application

1. Scenario
   - Capture images on RoboRio and run separate processing application (or integrated library) to extract features
     - e.g. GRIP(application) or IMAQ(library)
     - Can use inter-process or network communication protocols if image processing is carried out in a separate application
   - Use extracted image features to direct control
     - eg. Change angle for shooter target
   - Send Images up to driver station for user feedback
     - target areas in images could be annotated (surrounded by boxes etc.)
2. Pros
   - Simplest and cheapest to implement (since only one processor board is required)
   - Can use similar a strategy for simulation (since everything must run on the Linux host)
3. Cons
   - May run into processing bottleneck problems

Use a separate computer for image processing on deployed hardware

1. Scenario
   - Use RoboRio for Robot application
   - Use a second computer (e.g. Raspberry Pi or Jetson) for Image processing
     - Camera data only captured on processing board
   - Image processor extracts feature information and sends it to the RoboRio (e.g. via local ethernet)
   - Image processor sends raw or annotated images up to driver station
   - Roborio uses feature information to direct control

2. Pros
    - Uses an external processor to reduce computation overhead on RoboRio CPU
    - Has the potential to employ advanced object recognition algorithms such as NVIDIA cuDNN or openCV
3. Cons
    - Adds expense and complexity

Process raw images on host platform (driver station)

1. Scenario
    - Use RoboRio for Robot application
    - Send raw images from camera to driver station
    - Process images on driver station and extract features
    - Send feature information back to RoboRio to direct control
2. Pros
    - Can use high performance laptop to do the image processing
    - In Teleop mode the driver probably wants to see the camera images anyway
    - No extra hardware to buy
3. Cons
    - May suffer from network IO bottlenecks because of the need to transfer images from the RoboRio to the Driver Station laptop
        - In competition, radio bandwidth is limited (e.g. 7MB/s) which will reduce image frame rate for both Teleop and Autonomous modes
    - Requires a higher performance driver station computer
    - Since the host data station does not run a RTOS (it runs Windows 10) image processing latencies will be indeterminate

Simulation Strategies

At the present time all simulation processing needs to run on the same (multi-core) CPU in a Ubuntu 14.04 operating system environment. In addition, because of a bug in Gazebo that causes a loss of depth information in the (simulated) camera images, the computer needs to run Linux natively (e.g. in a separate boot partition) and be equipped with a middle to high end graphics card (e.g. an integrated

Intel GPU running Linux also exhibits the problem). The depth ordering bug is also evident when running Gazebo in a Virtual machine (under Windows) even on a system with a high end NVIDIA graphics card

Requirements

From a software point of view the vision interface to the Robot application should not require any (or much) special coding in order to run in the simulator or on real hardware

Strategy

- Capture a (simulated) camera publication from Gazebo and convert the image data to a form that can be input to an application like GRIP, raw openCV or an advanced API such as cuDNN
- Process the image using one of the tools mentioned above and extract relevant object position information such as center of mass, height, width etc.
- Pass the position information for the identified object (or objects) in a array of structures using a protocol that is also available on real hardware (e.g. the FRC NetworkTables protocol)
- Let the Robot application decide what to do with the object position data

Software SubSystems

GRIP

Notes for building and testing on Ubuntu 14.04

- note: GRIP can also be installed on Windows using an installer available on the WPI github site

References

1. https://wpilib.screenstepslive.com/s/4485/m/50711/c/150895

   GRIP "Alpha"
2. https://usfirst.collab.net/sf/projects/grip_computer_vision_engine/ (?)

   note: this doesn't appear to be the same source tree that is described in the screenstepslive web page above (orphaned project ?)
3. https://github.com/WPIRoboticsProjects/GRIP/wiki/Setting-up-build-tools

Installation

1. Clone the git repository

   git clone https://github.com/WPIRoboticsProjects/GRIP

   - creates a subdirectory GRIP in parent directory (i.e. where git clone was issued from)

Building and Launching

1. Build UI and Run from command line (instructions from README.md)

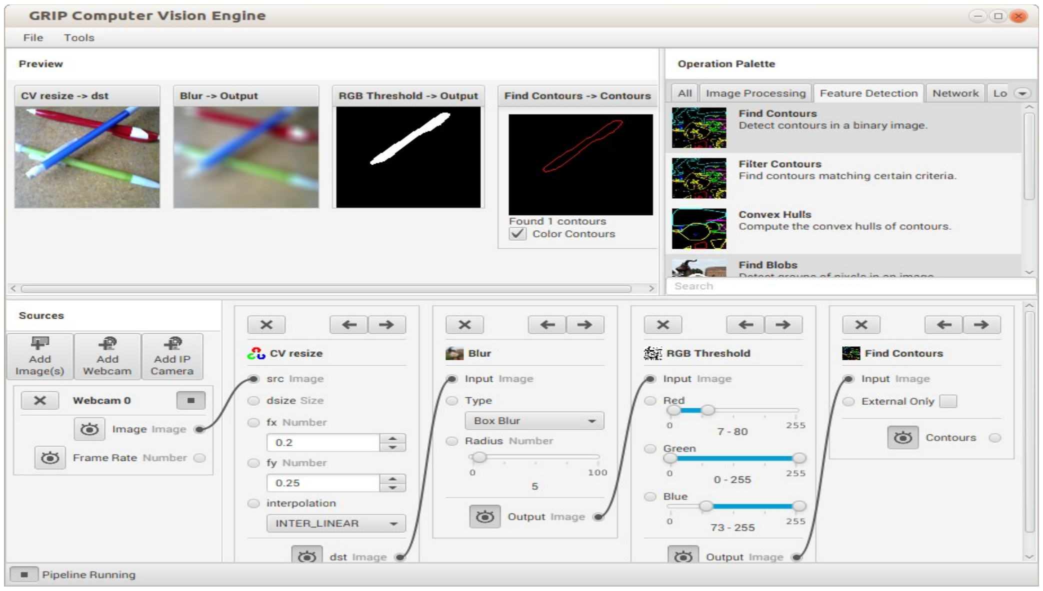
   ```
   $ ./gradlew :ui:run
   ```

Investigation Plan

1. Build and Run JavaFX GRIP GUI on Ubuntu
2. Develop interface between Gazebo output (Camera publication) and GRIP input (UI and headless)
   - Emulate webcam or mpeg stream input modes ?
3. Test or develop interface between GRIP output and Eclipse Robot application (FRCUserProgram)
   - In simulation mode everything runs on the CPU
   - In deploy mode FRCUserProgram runs on the RoboRIO (but will not test this)
4. Test or develop interface between GRIP output and Smart Dashboard
   - Smart Dashboard normally intercepts networkTables publications from FRCUserProgram
     - Q: Can SD also capture networkTables publications from GRIP ?

Tests

1. Find the Blue pencil using GRIP UI panel



Found 1 contours
✓ Color Contours

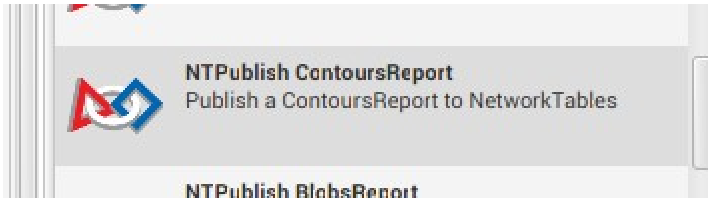
CV resize: fx Number 0.2; fy Number 0.25; interpolation INTER_LINEAR

Blur: Type Box Blur; Radius Number 5 (0–100)

RGB Threshold: Red 7 - 80; Green 0 - 255; Blue 73 - 255

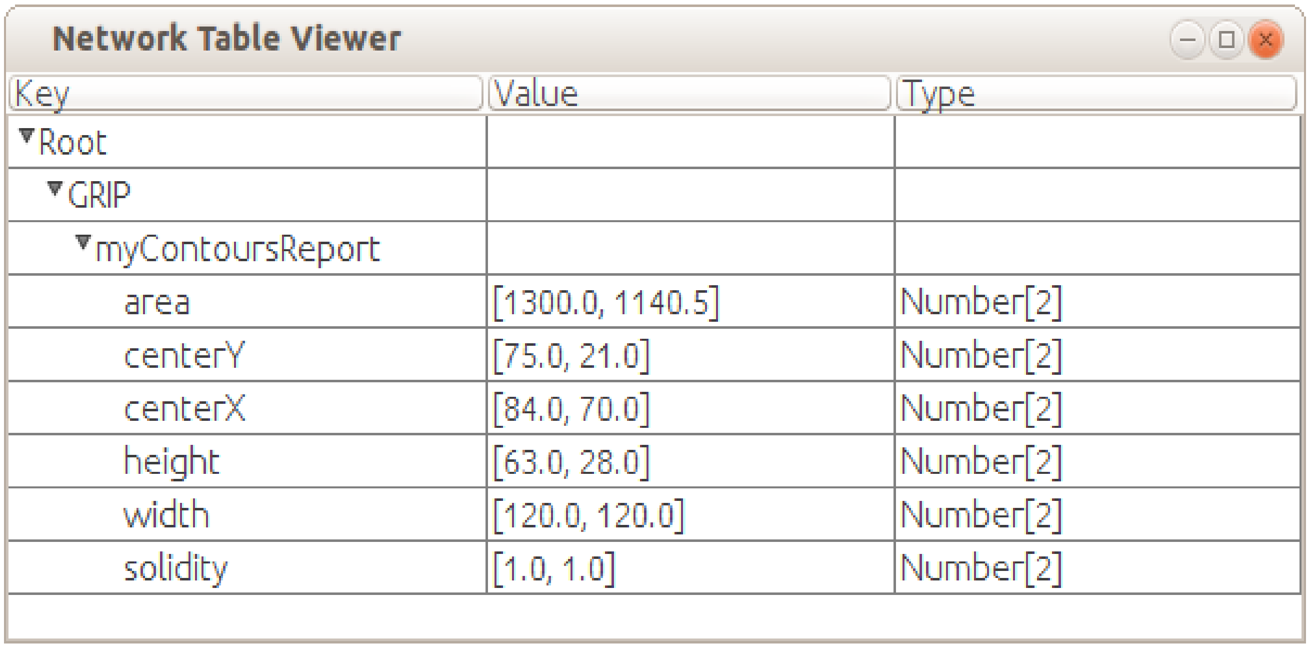
Find Contours: External Only ☐

2. Test Network tables publication
   - Add NTPublish CountoursReport panel and connect to “FindContours” panel



- Run “OutlineViewer”
  - $ java -jar ~/wpilib/tools/OutlineViewer.jar
  - Start “Server” (leave entry fields blank)

    note: If Server not started get “Connection refused error” in GRIP.log



Key	Value	Type
▾Root		
▾GRIP		
▾myContoursReport		
area	[1300.0, 1140.5]	Number[2]
centerY	[75.0, 21.0]	Number[2]
centerX	[84.0, 70.0]	Number[2]
height	[63.0, 28.0]	Number[2]
width	[120.0, 120.0]	Number[2]
solidity	[1.0, 1.0]	Number[2]

3. Capture GRIP NetworkTables publications in a Robot Program (linux_simulate build)

- Run the GRIP “Find blue pencil” project with the NTPublishContoursReport panel connected to the “FindContours” panel as described above
  - make sure “Publish area” is checked in the NTPublishContoursReport panel
- In Eclipse, write the following small “SampleRobot” program (e.g. in a FRC c++ project called GripTest):

```
class Robot: public SampleRobot {

public:
    std::shared_ptr<NetworkTable> table;
    Robot() {
        table = NetworkTable::GetTable("GRIP/myContoursReport");
    }
    void RobotInit() {
        static unsigned int old_area = 0;
        while (true) {
            std::vector<double> arr = table->GetNumberArray("area",
                    llvm::ArrayRef<double>());
            if (arr.size() > 0) {
                unsigned int new_area = (unsigned int) arr[0];
                if (new_area != old_area) {
                    std::cout << "area=" << new_area << std::endl;
                    old_area = new_area;
                }
            }
        }
    }
    void Autonomous() {
    }
    void OperatorControl() {
    }
    void Test() {
    }
};
START_ROBOT_CLASS(Robot)
```

- Compile “GripTest” using linux_simulate build
    - Generates FRCUserProgram in project's linux_simulate sub-directory

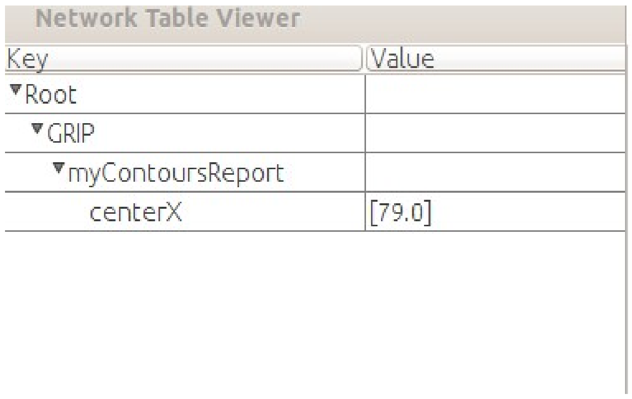
- In a command shell, start up gazebo
    - $ gazebo
    - note: not actually using gazebo in this case but FRCUserprogram wont start unless Gazebo is running
- In a command shell start up “FRCUserProgram”
    - cd GripTest/linux_simulate
    - $ ./FRCUserProgram
    - Example output in the command shell:

```
….
area=1000
area=998
area=778
area=967
….
```

4. Show data from GRIP ContoursReport in SmartDashboard
    - Start SmartDashboard

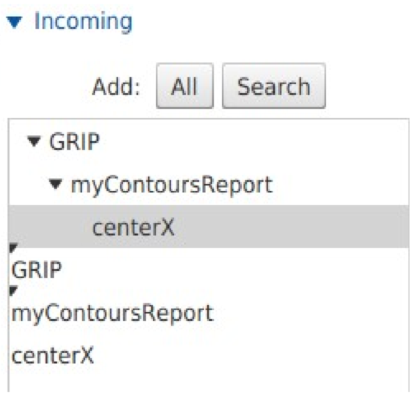
- java -jar ~/wpilib/tools/sfx

- Open Incoming list



Network Table Viewer

Key	Value
▼Root	
▼GRIP	
▼myContoursReport	
centerX	[79.0]

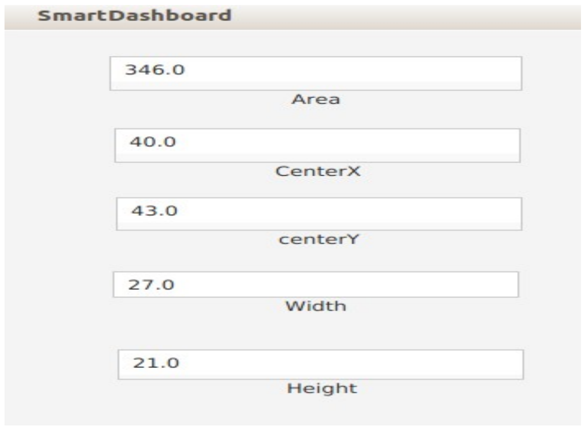


▼ Incoming

Add: All Search

▼ GRIP
▼ myContoursReport
centerX
GRIP
myContoursReport
centerX

- Drag an item (e.g. centerX) from "incoming" tree into panel (fails)
    - A Popup appears that offers a list of widget choices (e.g. number label,value meter etc.) but nothing gets generated in the panel
- Add an item manually (works)
    - open "+" ->Toolbox-general list and select "Array View" widget and drag to panel
    - double click array widget in panel and set Path to /GRIP/myContoursReport/centerX (etc.)
    - press labeler button and set label
        - "left" orientation doesn't resize column enough to show text but "bottom" seems to work (see below)



SmartDashboard

346.0
Area

40.0
CenterX

43.0
centerY

27.0
Width

21.0
Height

5. Build Smart Dashboard from source code

- Was able to checkout the SFX project(s) from wpi git repository:

  https://usfirst.collab.net/sf/scm/do/listRepositories/projects.smartdashboard2/scm

  but haven't yet been able to build it (note: needed to also get Netbeans 8.1 etc.)

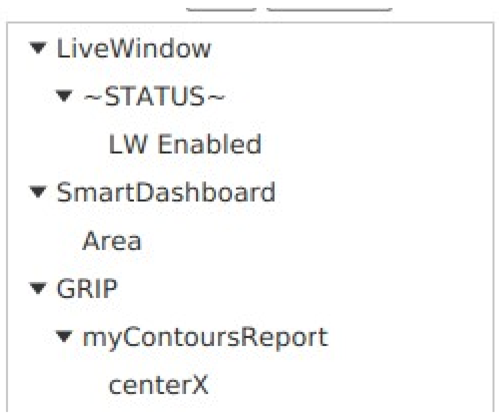
  There seems to be some missing or changed URLs used in the build scripts (e.g. build couldn't find netbeans plugins at ..usfirst.collab.net:29418/netbeans_plugins -> repository doesn't exist)

6. Show GRIP data routed through FRCUserProgram in SmartDashboard

- Added the following line to the sample robot program shown above that captures GRIP data:

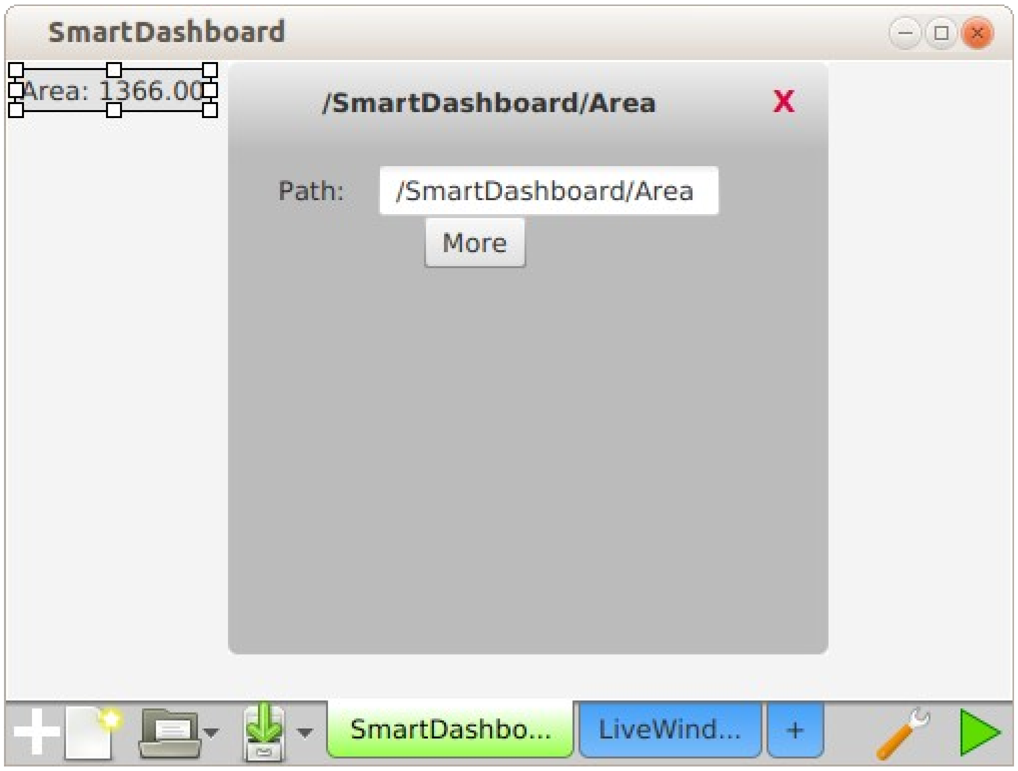
```
if (new_area != old_area) {
     std::cout << "area=" << new_area << std::endl;
  →  SmartDashboard::PutNumber("Area",new_area);
     old_area = new_area;
}
```

- built and started FRCUserProgram (and gazebo)
- Started SFX and opened "incoming" tab (now see SmartDashboard node in tree)



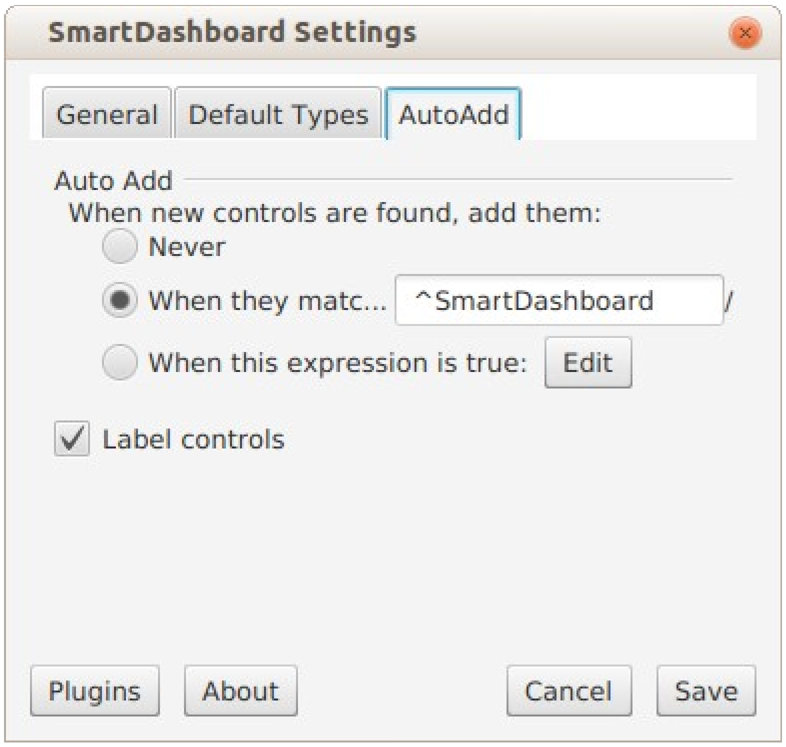
- Added a "number" label widget to canvas and set Path to /SmartDashboard/Area

- ○ GRIP "Area" numbers now get updated in data field



Path: /SmartDashboard/Area

- Can also cause "Area" widget to be automatically created on startup by changing AutoAdd settings as shown:

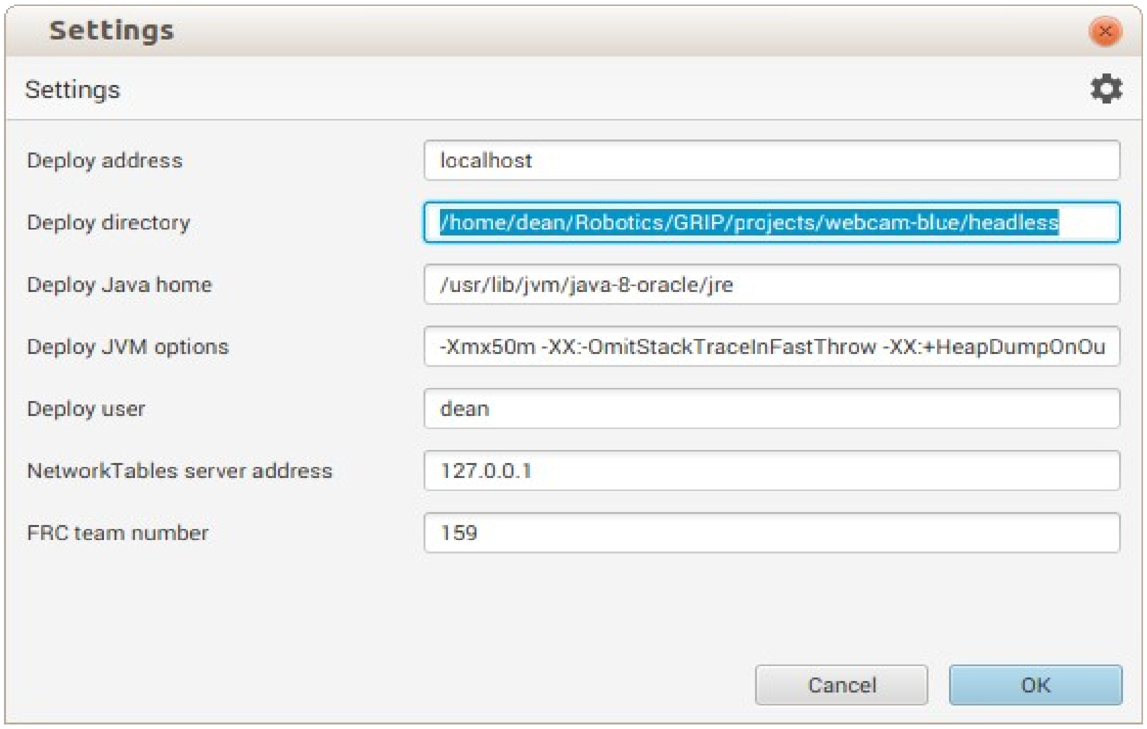


Auto Add
When new controls are found, add them:
Never [✓ When they matc... ^SmartDashboard /] When this expression is true:
[✓ Label controls]

7. Run GRIP ui from command line (i.e. not using gradlew)
   - $ gradlew :ui:installDist
     - creates startup shell script "ui" in GRIP/ui/build/install/ui/bin
   - $ ui/build/install/ui/bin/ui
     - starts up GRIP UI
   - $ ui/build/install/ui/bin/ui <path-to-project-file>
     - starts up GRIP UI and opens project file (e.g. project.grip)

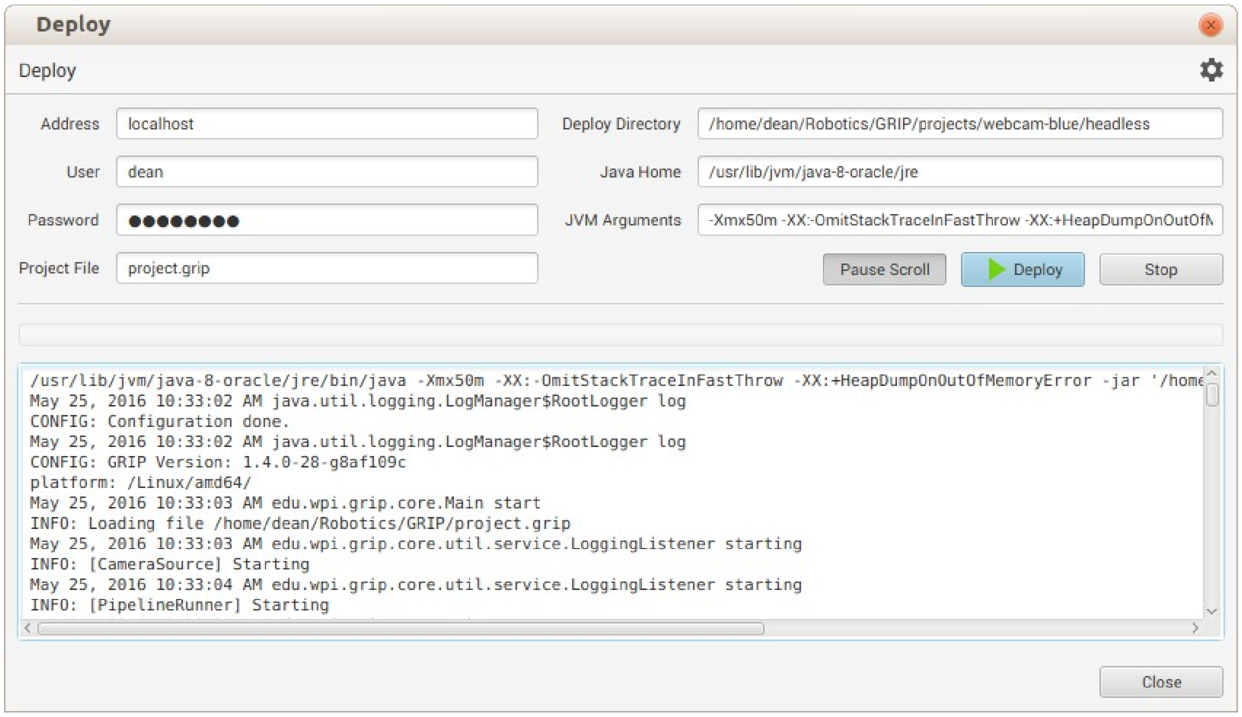
GRIP -2016

1. Setup and run "Headless" GRIP project from command line (on localhost)
   - Start up GRIP UI and load project (using any method described above)
   - Open <menu>Tools->"Settings" dialog



Deploy address	localhost
Deploy directory	/home/dean/Robotics/GRIP/projects/webcam-blue/headless
Deploy Java home	/usr/lib/jvm/java-8-oracle/jre
Deploy JVM options	-Xmx50m -XX:-OmitStackTraceInFastThrow -XX:+HeapDumpOnOu
Deploy user	dean
NetworkTables server address	127.0.0.1
FRC team number	159

   - Press <menu>Tools->Deploy
     - Brings up Deploy dialog



Address: localhost
User: dean
Password: ●●●●●●●●
Project File: project.grip
Deploy Directory: /home/dean/Robotics/GRIP/projects/webcam-blue/headless
Java Home: /usr/lib/jvm/java-8-oracle/jre
JVM Arguments: -Xmx50m -XX:-OmitStackTraceInFastThrow -XX:+HeapDumpOnOutOfN

```
/usr/lib/jvm/java-8-oracle/jre/bin/java -Xmx50m -XX:-OmitStackTraceInFastThrow -XX:+HeapDumpOnOutOfMemoryError -jar '/home
May 25, 2016 10:33:02 AM java.util.logging.LogManager$RootLogger log
CONFIG: Configuration done.
May 25, 2016 10:33:02 AM java.util.logging.LogManager$RootLogger log
CONFIG: GRIP Version: 1.4.0-28-g8af109c
platform: /Linux/amd64/
May 25, 2016 10:33:03 AM edu.wpi.grip.core.Main start
INFO: Loading file /home/dean/Robotics/GRIP/project.grip
May 25, 2016 10:33:03 AM edu.wpi.grip.core.util.service.LoggingListener starting
INFO: [CameraSource] Starting
May 25, 2016 10:33:04 AM edu.wpi.grip.core.util.service.LoggingListener starting
INFO: [PipelineRunner] Starting
```

   - Fill in password (for ssh access) and “Deploy Directory” field
   - Press the “Deploy” button
   - Creates a startup script (grip), a headless jar file (grip.jar) and project file (project.grip) in the directory specified by the “Deploy Directory” field
- Run headless grip with project file
   - $ cd projects/webcam-blue/headless/
   - $ grip
   - See same command line output as above (but no UI)

Comments

Pros

1. Intuitive user interface for testing the effect of common image processing operations
2. JavaFX UI can be built and deployed on both Linux and Windows (Mac?)
3. Can run “headless” on Raspberry Pi, Roborio or Jetson (purportedly)
4. Supports ROS (gazebo) and networkTables (First/WPI) publication protocols

5. Can extract and publish geometry information from contour lists (center, width etc.)

Cons

1. Current implementation doesn't support generalized object recognition through “learning” algorithms
   - Uses basic image processing functions like “blur”, edge extraction etc.
   - Similar to ni-vision (IMAQ)
2. GRIP documentation says GPU isn't supported on Jetson board (need to test)
3. On Raspberry Pi, problems with image publication require complicated workaround
4. Requires installing Java runtime on target platform
5. Java based (vs compiled binary), so processing speed may be an issue (?)

Problems

1. Can't figure out how to combine contours and original image
   - Want to see contours or convex hulls super-imposed on original image (e.g. for teleop mode)
   - Combining Original image with threshold output (as mask) is black everywhere except where mask is white
   - UI doesn't permit connection between original image and “contours” output as second image for any CV operations (bit-wise xor etc.)
   - No obvious tool to convert “Contours” or “Hulls” display back into RGB to make CV combine operators work
2. Image publication for display on Linux doesn't seem to work
   - May need GRIP code changes

GRIP – 2017

As of 2017, the recommended method for deploying GRIP on any target is to first generate a code segment from the GRIP Java UI (after tuning the filters etc. on a target) and then incorporating it directly into an application. The application can either be a part of the Robot program (FRCUserProgram), run as a separate thread on the RoboRio, or compiled for and run on a co-processor such as a Raspberry Pi or Jetson

Installation (Ubuntu)

Program Integration

Integration of the 2017 GRIP image processing pipeline into the Robot program differs from the Java based deploy method outlined in the previous section. Whether, incorporated as subsystem, thread or remote application the following general steps can be employed:

1. Build a GRIP target isolation filter on a development host (e.g. Ubuntu, Windows) using the JavaFX GUI as described above
2. Export a OpenCV code segment (C++,Java or python) using the new “export” feature in the user interface
   - for the c++ option two files (GripePipeline.h and GripPipeline.cpp) are produced
3. Incorporate the GripPipeline code into a remote application or thread
   - The c++ code snippet produced by the GRIP Ui doesn't contain any I/O calls so cannot be used without some modification
   - For local build On Ubuntu 14 (with openCV 3.1 installed) got a link Symbol Undefined error (and warnings about OpenCV 2.4 functions unless /usr/local/lib was added to the top of the link library list
4. Add a NetworkTables interface into both the robot program and GripPipeline application (or thread) to exchange configuration and target information.
5. Change the Robot build to include some additional dynamic libraries
   - RoboRio build: TalonSRXLib
   - Gazebo Simulation (local app or thread) : `ntcore, wpilibcSim, gz_msgs, gazebo_client, boost_system, CANTalon, opencv_core,opencv_core, opencv_imgproc, opencv_video, opencv_videoio`
   - Gazebo Simulation (for remote app): ntcore, wpilibcSim, gz_msgs, gazebo_client, boost_system, CANTalon, opencv_core
   - Remote host library list: `opencv_core, opencv_imgproc, opencv_video, opencv_videoio, cscore, CameraServer, ntcore`
6. Modify RobotInit code to configure or launch remote thread or application

Refer to “Team159-SimRobot-2017.pdf” in the MentorRepository/Sofrtare/Docs directory on Team 159's github page for detalis on how GRIP was incorporated into the 2017 “SteamWorks” game

OpenCV

Version: OpenCV 3.1

target system: Ubuntu 14.04

references

http://www.askaswiss.com/2016/01/how-to-install-opencv-3-1-python-ubuntu-14-04.html

Build from opencv git rep

1. Obtain active source code
   - $ git clone https://github.com/Itseez/opencv
   - cd opencv
   - git checkout tags/3.1.0 -b 3.1.0
     - note: master branch is actually at 2.4 which produces compile errors unless CUDA is disabled
2. configure
   - mkdir build && cd build
   - ccmake ..
     - select options
       - YES: WITH_CUDA, WITH_OPENGL, WITH_MP ..
     - press c (configure)
     - press g (generate)
3. build
   - make -j6 (takes ~ 1hr to build)

Test Installation

1. Build samples
   - $ cd ../samples
   - mkdir test && cd test
   - $ ccmake ../
     - set OPENCV_DIR to ~/opencv/build

        - set OPENCV_FOUND to YES
    - $ make -j6
2. Test
    - fix data paths so that samples will work using defaults
        - cd ~/opencv
        - cp -R data/* samples/data (training data needed for face-detect)
        - $ cd cpp
        - ln -s ~/opencv/samples/data ../data
    - $ cpp-example-facedetect data/lena.jpg
        - should see woman's head with face and eyes circled

Mjpg Streamer

Mjpg_steamer is a utility application that can be used to convert a set of images or the output of a USB WebCam into a TCP/IP data stream that can be input to an external application, web browser or GRIP (as an “ip camera”). It is a github project that can be build from source on most hardware/software platforms (including the Raspberry Pi)

1. Installation (Linux)
    - Obtain libraries and source code
        - sudo apt-get install libjpeg8-dev
        - git clone https://github.com/jacksonliam/mjpg-streamer.git
    - Build from source and install
        - cd mjpg-streamer/mjpg-streamer-experimental
        - make clean all
    - Install
        - sudo make install
2. Options
    - Show help/usage
        - mjpg_streamer [-i, -o] '<plugin-name> --help'

            - mjpg_streamer -i 'input_file.so –help'
            - mjpg_streamer -o 'output_http.so --help'
    - -f <path>
        - set path for saved jpeg files
        - e.g. : -f /tmp/shooter-camera
    - -r
        - remove jpeg files after reading (otherwise keep all files)
3. Tests
    1. pipe some jpg files in a directory to a web address
        - mjpg_streamer -i "input_file.so -f /home/dean/test/images -r -d 0.1" -o "output_http.so -w www -p 1180"
        - In Web browser (e.g. Firefox) capture and display images or image stream
            - e.g. Set web address to http://Ubuntu14.local:1180/?action=stream

Gazebo Simulation

Setup

1. Modify simulation FRC Robot sdf file

- `Add a "save" element in the sensor/camera block e.g:`

```
<sensor name='ShooterCamera' type='camera'>
      <visualize>1</visualize>
      <always_on>1</always_on>
      <update_rate>2</update_rate>
      <camera name='Shootercamera'>
            <save enabled="true">
            <path>/tmp/shooter-camera</path>
            </save>
      </camera>
</sensor>
```

- When the simulation is run this will generate a set of jpg files to appear in the “path” directory
- Use the “`update_rate” element in the sensor block to set the file capture frame rate`

Run Simulation

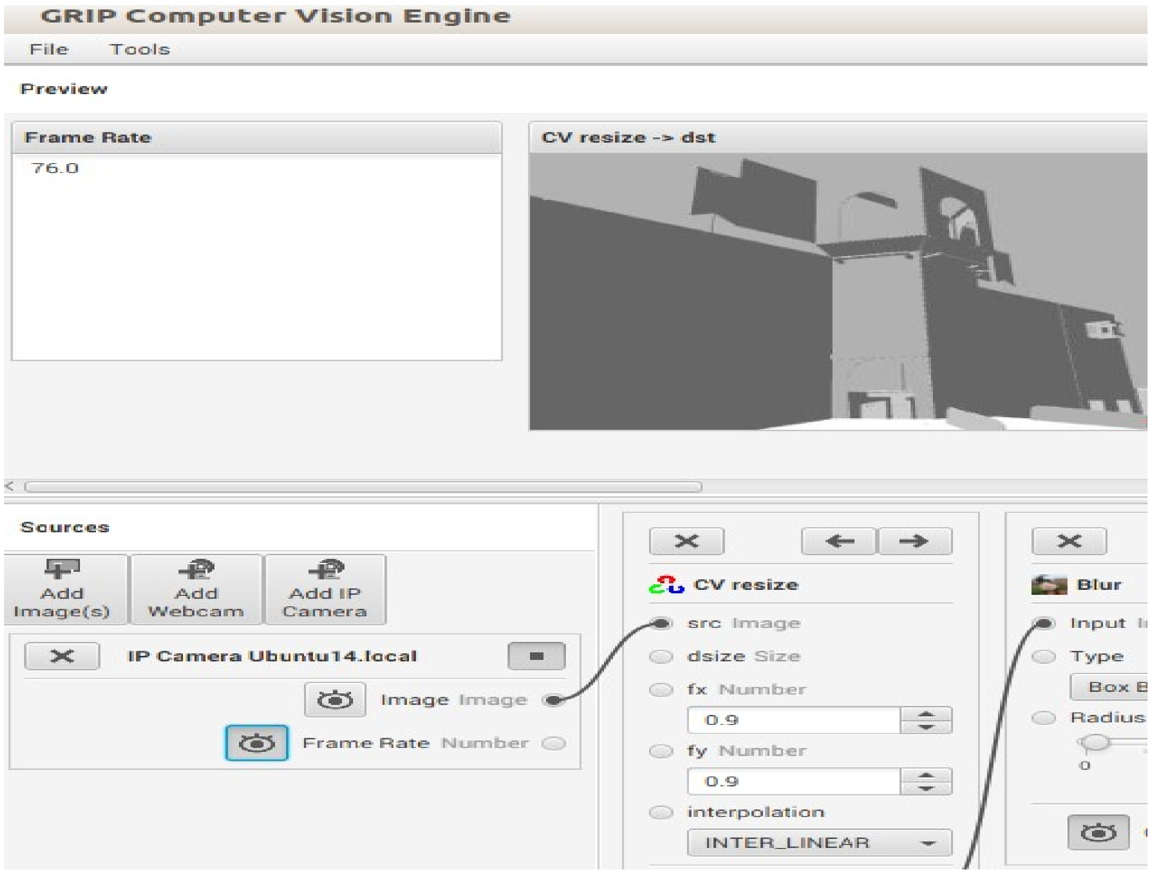
2. start mjpg-streamer with arguments that will generate an mpeg stream using the files in the indicated directory
   - rm -fr /tmp/shooter-camera
   - mkdir -p /tmp/shooter-camera
   - mjpg_streamer -i "input_file.so -f /tmp/shooter-camera -r -d 0.1" -o "output_http.so -w www -p 1180"
3. Start GRIP as described above and set input source to a new ip camera with local URL

   `e.g.` `http://Ubuntu14.local:1180/?action=stream`
4. Start Gazebo Robot simulation as described previously (__ref__)
   - cd to FRC Robot project and run startup script e.g.:

     ```
     # start gazebo
     export SWMODEL=$SWEXPORTS/2016-Robot_Exported
     export GAZEBO_MODEL_PATH=$SWMODEL:$WPILIB/simulation/models:/usr/share/gazebo-6.5/models
     gazebo --verbose $SWMODEL/2016-Robot-field.world
     ```
   - Connect Joystick or Gamepad and start sim_ds
     - $sim_ds
   - Start FRCUserProgram
     - $ cd <path-to-robot-project>/linux_simulate
     - $ ./FRCUserProgram

First Results

1. Screenshot of Gazebo simulation of shooter camera on team 159's 2016 robot in FRC Stronghold Challenge field



Frame Rate
76.0

fx Number: 0.9
fy Number: 0.9
interpolation: INTER_LINEAR

Improvements

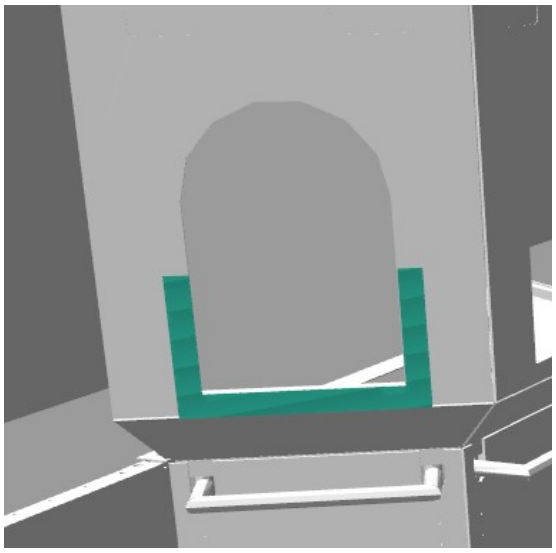
Add colored tape strips around tower targets

1. Create a tape pattern sdf file using solidworks exporter
   - Create a sketch with bottom = 18”, sides=12”, tape width=2”
   - Create a part then assembly from sketch
   - Extrude sketch a slight amount (e.g. ~0.1”)
   - Generate reference properties for origin, baseplane and axis
   - Use gazebo exporter tab “edit model” to set properties
     - Set name to TapePattern
     - Set origin, baseplane and axis using reference objects created previously
     - Select extruded sketch as base joint
     - Set color

- Export model

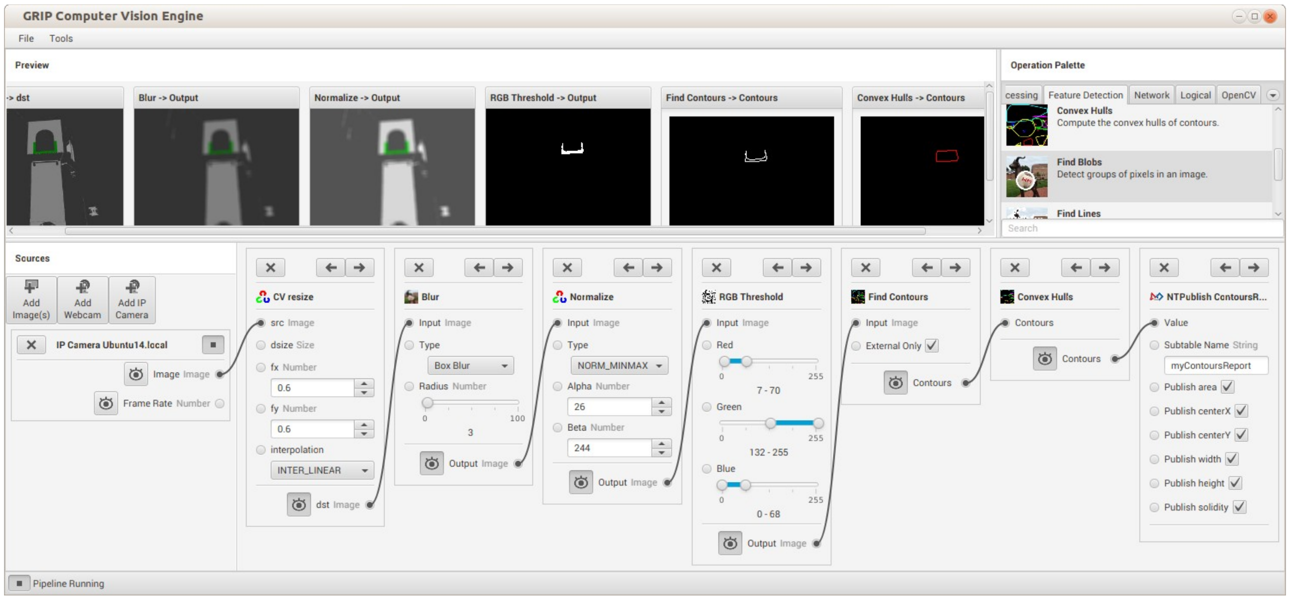
2. Modify sdf file (hand edit)
   - Remove collision and inertia elements and set gravity=0
     - otherwise object will drop to the ground when physics is enabled
   - Edit ambient and diffuse colors if needed
     - for test purposes first try setting color to pure green(rgb=0,1,0)
3. Add TapePattern object to Robot simulation world file
   - Start Gazebo with world file containing robot and FRC field
   - Stop physics simulation
   - Insert a “TapePattern” object into gazebo
   - Use Position and Rotate modes to move TapePattern object to correct position below window in Turret
   - Select the TapePattern item in the world tree and Copy down “pose” settings
   - Exit gazebo
   - Edit the robot world file to add a tape pattern object with the correct pose e.g.:

     ```
     <include>
       <uri>model://TapePattern</uri>
       <pose>0.125288 -7.62138 2.11 0.000148 0.000257 0.52429</pose>
     </include>
     ```
   - Screenshot of tape pattern in left turret



Optimize GRIP Processing blocks to identify tape pattern target

1. Start up mgpg-streamer (monitor image dump directory)
2. Start up Gazebo Robot-FRC field simulation
3. Start up GRIP and set source to ip camera (use local host as URL)
4. In Gazebo teleop mode drive robot to location of tower and adjust shooter angle until target is visible in GRIP input window
5. Set processing blocks in GRIP
   - IP Camera input source (receiving data from mjpg-streamer)
   - resize (optional)
   - blur (kernel size=3)
   - normalize (default settings)
   - RGB Threshold (optimized for pure green tape pattern)
   - find contours (external only)
   - convex hulls
   - NT Publish Contours



Convex Hulls: Compute the convex hulls of contours.
Find Blobs: Detect groups of pixels in an image.
Find Lines

IP Camera Ubuntu14.local
- Image Image
- Frame Rate Number

CV resize
- src Image
- dsize Size
- fx Number: 0.6
- fy Number: 0.6
- interpolation: INTER_LINEAR
- dst Image

Blur
- Input Image
- Type: Box Blur
- Radius Number: 3 (0–100)
- Output Image

Normalize
- Input Image
- Type: NORM_MINMAX
- Alpha Number: 26
- Beta Number: 244
- Output Image

RGB Threshold
- Input Image
- Red: 7 - 70 (0–255)
- Green: 132 - 255 (0–255)
- Blue: 0 - 68 (0–255)
- Output Image

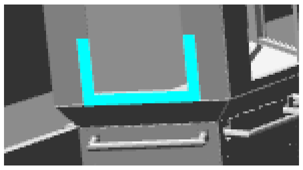
Find Contours
- Input Image
- External Only ✓
- Contours

Convex Hulls
- Contours
- Contours

NTPublish ContoursR...
- Value
- Subtable Name String: myContoursReport
- Publish area ✓
- Publish centerX ✓
- Publish centerY ✓
- Publish width ✓
- Publish height ✓
- Publish solidity ✓

Optimize lighting to match FRC field environment

1. Q: Is it possible to add a light source to the Robot ?
   - A: No, not with latest version of Gazebo (but is a feature request)
2. Q: Is illumination supported as an sdf material property ?
   - A: Yes, set “emissive” property in material element
   - e.g. <emissive>0.0 1.0 1.0 1</emissive>

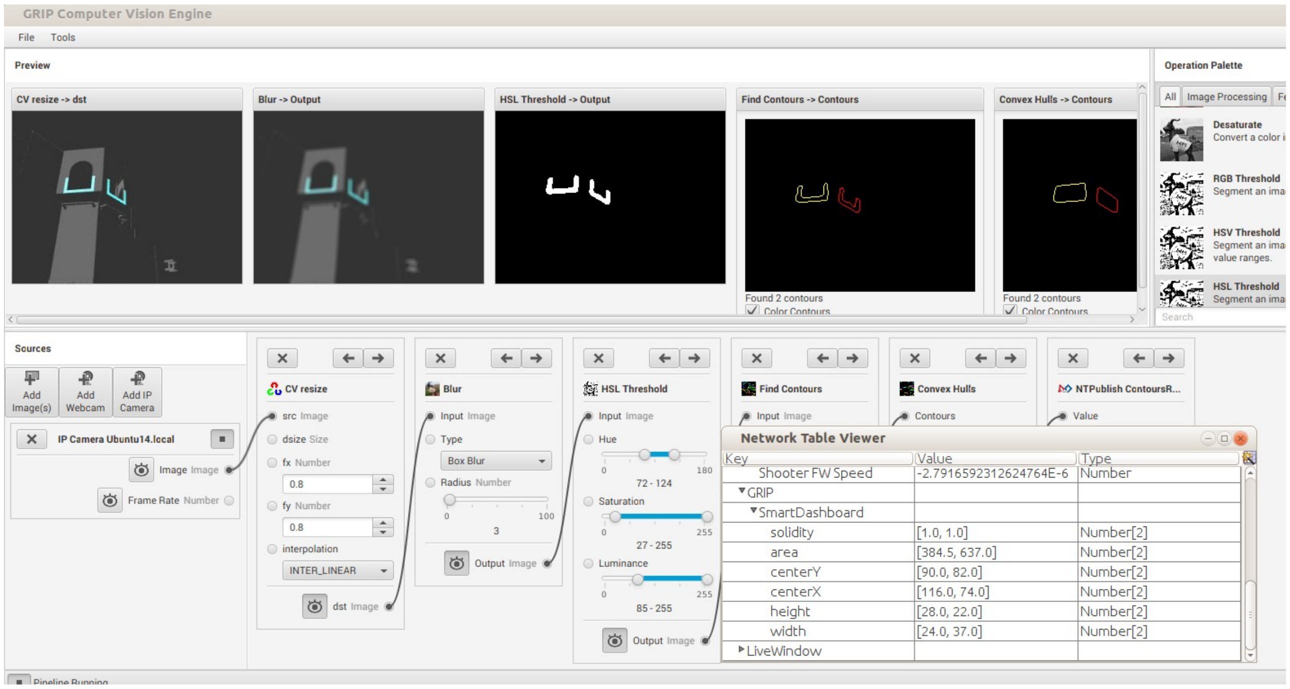


3. Determine best color for tape pattern
   - ambient and diffuse =1,1,1,1
   - <emissive>0.2 1.0 1.0 1</emissive>
4. Q: Is it possible to modify simulated camera properties such as “exposure” and “brightness” ?
   - Need to check
   - Can emulate effect by darkening scene lighting
5. Modify Gazebo ambient lighting properties be better emulate inside environment
   - Disable global shadows
   - Darken field environment by (e.g.) changing rgb diffuse color values from 0.8 to 0.5

Improved Results

1. Added second tape pattern to center turret

2. Processing blocks
    - Got better contour isolation by using HSL vs RGB threshold block
    - Removed Normalize block
3. Screenshot of GRIP UI with improved target lighting



Found 2 contours
Color Contours

Found 2 contours
Color Contours

IP Camera Ubuntu14.local
Image Image
Frame Rate Number

CV resize
src Image
dsize Size
fx Number 0.8
fy Number 0.8
interpolation INTER_LINEAR
dst Image

Blur
Input Image
Type Box Blur
Radius Number 3
Output Image

HSL Threshold
Input Image
Hue 72 - 124
Saturation 27 - 255
Luminance 85 - 255
Output Image

Find Contours
Input Image

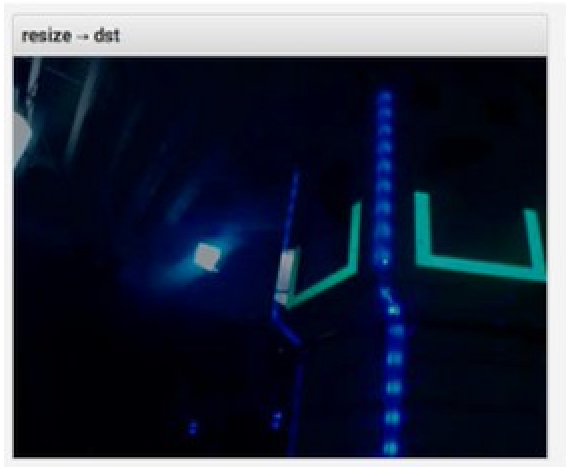
Convex Hulls
Contours

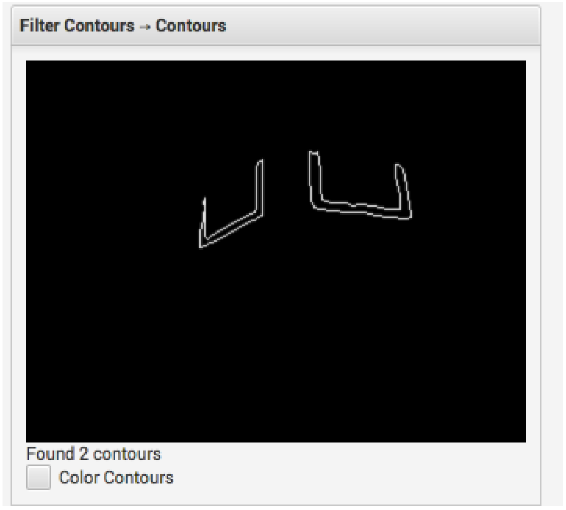
NTPublish ContoursR...
Value

Network Table Viewer

Key	Value	Type
Shooter FW Speed	-2.7916592312624764E-6	Number
▾GRIP		
▾SmartDashboard		
solidity	[1.0, 1.0]	Number[2]
area	[384.5, 637.0]	Number[2]
centerY	[90.0, 82.0]	Number[2]
centerX	[116.0, 74.0]	Number[2]
height	[28.0, 22.0]	Number[2]
width	[24.0, 37.0]	Number[2]
▸LiveWindow		

4. Comparison with real FRC field results
    - reference: http://wpilib.screenstepslive.com/s/4485/m/50711/l/481750-using-grip-for-the-2016-game





TODO

1. Modify Solidworks Gazebo exporter plugin to provide entry fields for jpeg output path to avoid having to hand edit sdf files

Jetson TK1

Setup

1. Hardware version
   - Tegra K1
     - ARM® Cortex™-A15 CPU   (32 bit)
   - price: $192, NVIDIA
2. Software
   - Linux tegra-ubuntu
   - kernel: 3.10.40 SMP PREEMPT
3. Cables etc.
   - AC Power Adapter
   - Ethernet cable (to switch)
   - USB to micro-USB cable
   - note: Jetson has a built-in 16 GB flash memory

OS Installation

1. Setup
   - In order to view or download documentation you need to first register as an NVIDIA developer and then become a member of the "Embedded Computing" group
   - Then go to the NVIDIA Download site and download
     - "Jetson TK1 User guide"
     - "Jetpack for L4T (Ubuntu 64 bit)"
       - https://developer.nvidia.com/embedded/dlc/jetpack-l4t-2_2
       - Downloads: JetPack-L4T-2.2-linux-x64.run

2. References

   - Follow Instructions in TK1 user guide for flashing OS

Remote Desktop (VNC)

Setup VNC server and VirtualGL

1. References

   - https://devtalk.nvidia.com/default/topic/828974/embedded-systems/-howto-install-virtualgl-and-turbovnc-to-jetson-tk1/

2. log onto Jetson

   - ssh -l ubuntu tegra-ubuntu.local
   - password is “ubuntu”

3. Install TurboVNV and VirtualGL on Jetson

   - log onto Jetson
   - Install pre-compiled ARM binaries given in reference

```
wget http://demotomohiro.github.io/hardware/jetson_tk1/pkg/libjpeg-
turbo_1.4.2_armhf.deb
wget http://demotomohiro.github.io/hardware/jetson_tk1/pkg/virtualgl_2.4.1_armhf.deb
wget http://demotomohiro.github.io/hardware/jetson_tk1/pkg/turbovnc_2.0.1_armhf.deb

sudo dpkg -i libjpeg-turbo_1.4.2_armhf.deb
sudo dpkg -i virtualgl_2.4.1_armhf.deb
sudo dpkg -i turbovnc_2.0.1_armhf.deb
```

   - Add jpeg to library path

```
sudo vi /etc/ld.so.conf.d/libjpeg-turbo.conf
add the following line: /opt/libjpeg-turbo/lib32
```

   - Install xfce4 Desktop (optional)

```
sudo apt-get install xfce4 xfce4-goodies gnome-icon-theme-full
```

   - Configure vncserver (a dialog appears on first time launch of vncserver)
     - `start vncserver`
       - `/opt/TurboVNC/bin/vncserver`
       - Can answer “no” to questions about VNC user group etc.
       - Creates a ~/.vnc/xstartup.turbovnc file in home directory
     - `stop (kill) vncserver`

        - `/opt/TurboVNC/bin/vncserver -kill :1`

- Set vnc preferences for remote display

```
vi .vnc/xstartup.turbovnc

add  lines:

unset SESSION_MANAGER
unset DBUS_SESSION_BUS_ADDRESS
startxfce4 &
```

- Modify xorg.conf (add a ”Screen” section)

```
$ sudo vi /etc/xorg.conf
```

- `add:`

```
Section "Screen"
   Identifier  "Screen0"
   Device "Tegra0"
   Monitor "DSI-0"
   Option "AllowEmptyInitialConfiguration"
   Option "UseEdid" "False"
EndSection
```

4. Configure Jetson to automatically start up a vncserver session (:1) on boot

   - `sudo vi /etc/sysconfig/tvncservers`
   - add the following 2 lines:

   ```
   VNCSERVERS="1:ubuntu"

   VNCSERVERARGS[1]="-geometry 800x600” (optional)
   ```

   - `sudo update-rc.d tvncserver defaults`
   - `To disable automatic startup on boot:`
     - `sudo update-rc.d tvncserver disable`
   - `To re-enable automatic startup on boot:`
     - `sudo update-rc.d tvncserver enable`

Test OpenGL Samples

1. Install TurboVNV [VirtualGL] on Ubuntu desktop

   - Download and install TurboVNC

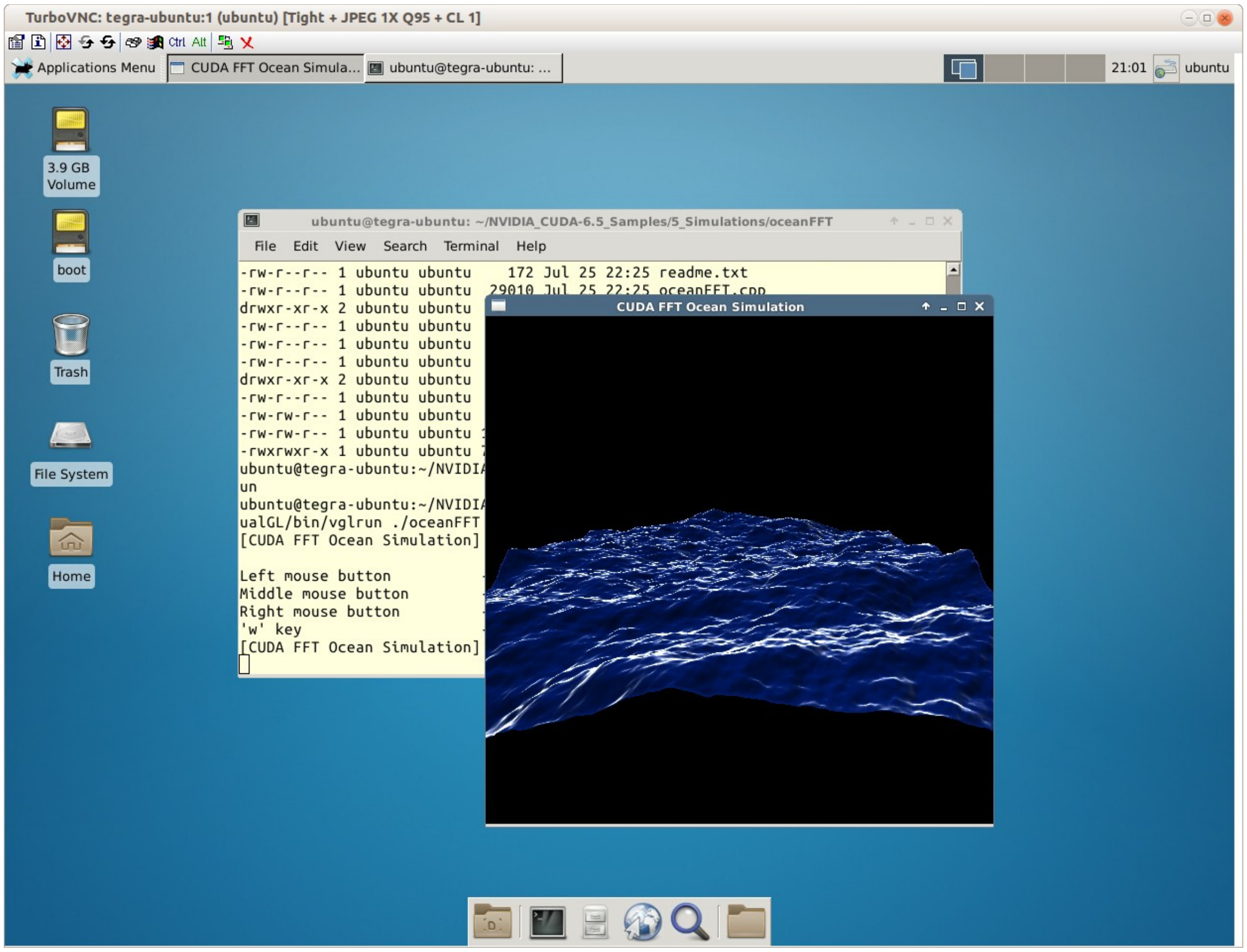
   - Download and install VirtualGL (optional)

2. Compile NVIDIA samples on Jetson

   - Log on to Jetson from Ubuntu host

        - ssh -l ubuntu tegra-ubuntu.local
    - Build all samples
        - cd NVIDIA_CUDA-6.5_Samples
        - make -j4

3. Set VNC connection from Ubuntu desktop to Jetson
    - On Jetson, vncserver should be running after a rebooting (see 3 above)
        - If not, start up a server session manually
        - /opt/TurboVNC/bin/vncserver :1
    - On Ubuntu desktop connect to vncserver running on the Jetson
        - /opt/TurboVNC/bin/vncviewer tegra-ubuntu.local:1
        - Should see Jetson xfce4 desktop in new window
            - note: the icon list at the bottom is sometimes blank (or other graphics problems). restarting the Jetson and the vncviewer may the problem (?)
4. Running Samples
    - from vncviewer window of Jetson desktop on Ubuntu14 host open a terminal
        - note: originally the terminal was “black on black” so the cursor wasn't visible until I changed the color preferences
    - cd to Example directory
        - cd ./NVIDIA_CUDA-6.5_Samples/5_Simulations/oceanFFT
        - `/opt/VirtualGL/bin/vglrun ./oceanFFT`


TurboVNC: tegra-ubuntu:1 (ubuntu) [Tight + JPEG 1X Q95 + CL 1]
Applications Menu
CUDA FFT Ocean Simula...
ubuntu@tegra-ubuntu: ...
21:01
ubuntu
3.9 GB Volume
boot
Trash
File System
Home
ubuntu@tegra-ubuntu: ~/NVIDIA_CUDA-6.5_Samples/5_Simulations/oceanFFT
File
Edit
View
Search
Terminal
Help
CUDA FFT Ocean Simulation

```
-rw-r--r-- 1 ubuntu ubuntu    172 Jul 25 22:25 readme.txt
-rw-r--r-- 1 ubuntu ubuntu  29010 Jul 25 22:25 oceanFFT.cpp
drwxr-xr-x 2 ubuntu ubuntu
-rw-r--r-- 1 ubuntu ubuntu
-rw-r--r-- 1 ubuntu ubuntu
-rw-r--r-- 1 ubuntu ubuntu
drwxr-xr-x 2 ubuntu ubuntu
-rw-r--r-- 1 ubuntu ubuntu
-rw-rw-r-- 1 ubuntu ubuntu
-rw-rw-r-- 1 ubuntu ubuntu 1
-rwxrwxr-x 1 ubuntu ubuntu 7
ubuntu@tegra-ubuntu:~/NVIDIA
un
ubuntu@tegra-ubuntu:~/NVIDIA
ualGL/bin/vglrun ./oceanFFT
[CUDA FFT Ocean Simulation]

Left mouse button
Middle mouse button
Right mouse button
'w' key
[CUDA FFT Ocean Simulation]
```

5. Performance comparison (Jetson vs GTX 980 on Ubuntu host)

   - Sample : smokeParticles
   - FPS (GTX 980): 60 (pegged to max update rate)
     - NVIDIA "Samples" directory was version 7.5 (vs. 6.5 on Jetson)
   - FPS (Jetson) : 8
     - FPS increased to 16 when window size was maximally reduced

CUDA SDK

1. References

- https://petewarden.com/2014/10/25/how-to-run-the-caffe-deep-learning-vision-library-on-nvidias-jetson-mobile-gpu-board/

2. The reference describes how to download and install `cuda-repo-l4t-r19.2_6.0-`

`42_armhf.deb` but this was skipped because a later version (`cuda-repo-l4t-r21.3-6-5-local_6.5-50_armhf.deb)`is present (in ~/cuda-l4t) and seems to already be installed

3. Set PATH and LD_LIBRARY_PATH in ~/.profile
   - export PATH=`/usr/local/cuda/bin:$PATH`
   - export LD_LIBRARY_PATH=/usr/local/cuda/lib:$LD_LIBRARY_PATH
   - . ~/.profile
4. Verify that nvcc is installed
   - nvcc -V

```
nvcc: NVIDIA (R) Cuda compiler driver
Copyright (c) 2005-2014 NVIDIA Corporation
Built on Tue_Feb_17_22:53:16_CST_2015
Cuda compilation tools, release 6.5, V6.5.45
```

cuDNN

1. Installation
   - After the OS-Jetpack” installation there is a directory called cudnn in ~/ so it looks like cudnn (version 2) is already installed
2. Test
   - $ cd cudnn/cudnn-sample-v2
   - $ make
     - builds mnistCUDNN
   - $ ./mnistCUDNN

```
Performing forward propagation ...
Result of classification: 1 3 5
….
Test passed!
```

OpenCV

1. Installation

- There is a directory called OpenCV4Tegra in ~/ so it looks like OpenCV is already installed

2. Verify installation
   - cd ~/OpenCV4Tegra
   - ./ocv.sh

     ….

     Reading state information... Done

     libopencv4tegra is already the newest version.

     libopencv4tegra-dev is already the newest version.
3. Note: This version of OpenCV is based on 2.4 and is optimized for the TK1 hardware (but may be too old to build projects that use more recent opencv features)

Caffe

Build

1. References
   1. https://petewarden.com/2014/10/25/how-to-run-the-caffe-deep-learning-vision-library-on-nvidias-jetson-mobile-gpu-board/
   2. http://jetsonhacks.com/2015/01/20/nvidia-jetson-tk1-cudnn-install-caffe-example/
   3. http://planspace.org/20150614-the_nvidia_jetson_tk1_with_caffe_on_mnist/
2. Install libraries

```
sudo apt-get install cmake libleveldb-dev libsnappy-dev
sudo apt-get install libprotobuf-dev protobuf-compiler
sudo apt-get install libboost-thread-dev libboost-system-dev
sudo apt-get install libatlas-base-dev libhdf5-serial-dev libgflags-dev
sudo apt-get install libgoogle-glog-dev liblmdb-dev
```

3. Install git
   - `sudo apt-get install -y git`
4. Clone caffe git repo
   - `git clone https://github.com/BVLC/caffe.git`
   - reference says to check out the “dev” branch but that seems to no longer exist

5. Build caffe (master branch)
    - following reference, installed g++ 4.7 to workaround some reported build problems with 4.8
        - sudo apt-get install gcc-4.7 g++-4.7
    - `customize Makefile`
        - `cd caffe`
        - `cp Makefile.config.example Makefile.config`
        - `sed -i "s/# CUSTOM_CXX := g++/CUSTOM_CXX := g++-4.7/" Makefile.config`
        - `vi Makefile.config`
        - `Uncommented “USE_CUDNN := 1”`
    - `make -j4`
        - `get compile errors: CUDNN_PROPAGATE_NAN undeclared etc.`
    - Did a web search and it looks like the master BVLC branch of caffe isn't compatible with cudnn v2 (which is what gets installed on TK1 by Jetpack 2.2)
        - tried checking out tag “rc2” from Berkley caffe site but that also failed to compile
        - Also got build problems when building from NVIDIA github site: https://github.com/NVIDIA/caffe
        - finally found an alternate site which is compatible with cudnn v2:
            - git clone https://github.com/slayton58/caffe
    - Rebuilt from alternate repo with success
        - `make -j4`
        - note: Also didn't need to modify `Makefile.config to use g++ 4.7`

Test

1. Build and run “runtest”
    - $ make -j4 runtest
    - Passed many tests but ultimately failed with: MDB_MAP_FULL error
    - Found a workaround on web at: http://jetsonhacks.com/2015/01/17/nvidia-jetson-tk1-caffe-deep-learning-framework/

    - change ../examples/mnist/convert_mnist_data.cpp:89:56
    - CHECK_EQ(mdb_env_set_mapsize(mdb_env,), MDB_SUCCESS)
    - to: CHECK_EQ(mdb_env_set_mapsize(mdb_env, 536870912), MDB_SUCCESS)
  - Rebuild and run examples
    - $ make

      CXX examples/mnist/convert_mnist_data.cpp

      CXX/LD -o .build_release/examples/mnist/convert_mnist_data.bin
    - $ make -j4 runtest
      - still fails (same error)
    - Try a clean caffe build
      - $ make clean
      - $ make -j4 all
        - got number overflow warning for: found another src/caffe/util/db_lmdb.cpp
        - again changed value from 1099511627776 to 536870912
      - $ make -j4 all
        - this time ran to completion
    - $ make -j4 runtest
      - probably ok now (had to leave after watching it run for over an hour and on return was loggod out from Jetson – maybe because screen saver kicked in at some point ?)

2. Performance tests (from reference 1)
   - syntax: build/tools/caffe time -model=models/bvlc_alexnet/deploy.prototxt [-gpu=0]
     - Syntax reported in reference (--gpu, --model) didn't work (need to use -model, -gpu)
     - add -gpu=0 to run with GPU support (else uses CPU)
   - Jetson TK1 (USE_CUDNN := 1)
     - GPU
       - Often seems to hang on “Performing Forward” (no output to screen)

        - Average Forward-Backward: 525.371 ms.
        - Value reported in reference 1 : 337.86
        - Value reported in reference 2 : 517.052 ms
    - CPU
        - Average Forward-Backward: <u>10764.6 ms.</u>
        - Value reported in reference 1: 585 ms
        - note: Observed “Average” result <u>significantly</u> (x20) worse than that reported in the references
    - GPU/CPU speedup = 20.5
- Jetson TK1 (# USE_CUDNN := 1)
    - Average Forward-Backward:
        - GPU: 513.565 ms
        - CPU: 10754 ms
- Jetson TK1 (# USE_CUDNN := 1 CPU_ONLY := 1)
    - Forward-Backward: 10896 ms
- GTX 980 GPU on AMD Phenom-II CPU
    - cudnn 5.1, CUDA 7.5, caffe (latest master branch)
    - GPU: 16.8638 ms.
    - CPU: 3320.1 ms
    - GPU/CPU speedup = 207
- Comments
    - No GPU speedup was observed with cuDNN (v2) enabled
    - GPU performance was comparable (but slightly worse) to that reported elsewhere
    - CPU only performance was **<u>20x</u>** worse than that reported elsewhere (??)
        - not much change when configuring cpu for “max performance” e.g. as described in: http://elinux.org/Jetson/Performance

Support for GRIP 2017

Java 8

1. Installation

- reference: http://elinux.org/Jetson/JavaFX
    - From Oracle download java 8 JDK for ARM (32 bit version)
    - install (untar using -C) to /opt/jdk1.8.0_131
    - install (unzip using -d) Jdk1.8.0 40-SNAPSHOT-lib.zip from reference to opt/jdk1.8.0_131/jre/lib/

2. environment setup

- add to ~/.bashrc: export JAVA_HOME=/opt/jdk1.8.0_131

ntcore

1. download source code from github

- git clone https://github.com/wpilibsuite/ntcore

2. build and install

- > mkdir -p ~/ntcore/build && cd ~/ntcore/build
- > make

3. install

- > sudo make install

cscore

Cscore is a wpi ibrary that contains a c++ API to raw OpenCV calls and is used by CameraServer etc. Unfortunately, it is difficult to build for remote targets (because the gradle build scripts are not well supported) and the prepackaged Maven variants can lead to an application crash (specific CameraServer::GetInstance() results in a core dump when it invokes the constructor for `cs::VideoListener)`

1. Plan A: Compile on Jetson natively
    - One problem is that the arm on the Jetson is a 32 bit device whereas the native build scripts seem to assume 64 bits when the build target is "native"
        - gmock:compileGmockX86SharedLibraryGmockCppg++: error: unrecognized command line option -m32

    - native:linkCscoreSharedLibrary/home/ubuntu/cscore/native/build/wpiutil/Linux/amd64/libwpiutil.a: error adding symbols: File format not recognized
- A method that works is to run a build using an ARM compiler on the Jetson (even though the resident g++ should also be arm based)
    - modified cscore/toolchains/arm.gradle and changed line 4 to:

      ```
      def compilerPrefix = project.hasProperty('compilerPrefix') ? project.compilerPrefix : 'arm-linux-gnueabihf-'
      ```

        - assumes that arm build tools were installed in /usr/bin
    - then run:
        - $ gradlew arm:build

2. Alternate B: Compile on Ubuntu 14.04 host using a cross compiler
    - followed instructions for cross-compile on this site:https://github.com/wpilibsuite/cscore
    - downloaded and tried to compile library with c++ 5 and 6 arm toolchains but got errors about -rdynamic and -pthread arguments
    - was able to obtain a 4.9 arm cross-compiler toolchain from
        - wget -c https://releases.linaro.org/archive/14.09/components/toolchain/binaries/gcc-linaro-arm-linux-gnueabihf-4.9-2014.09_linux.tar.xz
    - compile succeeded with this tool chain
        - after commenting out 2 code references to V4L2_CAP_DEVICE_CAPS and V4L2_CTRL_TYPE_INTEGER_MENU (symbols not defined)
    - but link failed with many errors
        - it looks like gradle build is trying to link in some 64bit downloaded arm libraries (libwpiutil.a,libwpiutil.so)
    - hack to fix wpiutil library problem
        - used the following build line to compile with "armhf" maven packages and 4.9 cross-compiler:

          ```
          gradlew :arm:build -PtoolChainPath=/usr/local/gcc-linaro-arm-linux-gnueabihf-4.9-2014.09_linux/bin -PcompilerPrefix=arm-linux-gnueabihf- -ParmSuffix=hf
          ```

        - gets further but ends with error:

        - :arm:downloadWpiUtil FAILED
        - Could not find wpiutil-armhf.zip (edu.wpi.first.wpilib:wpiutil:1.0.2-20170209040313-1-ge665632)
    - noticed that http://first.wpi.edu/FRC/roborio/maven/release/edu/wpi/first/wpilib/wpiutil/1.0.2/wpiutil.1.02-armhf.zip is a little older than the -arm.zip version (1/10/17 vs 2/17/17) which may be incompatible with the "lastUpdated" string in the parent directory (20170217101616)
    - fix gradle build to not try to download incompatible library
        - download older 1.02 library from: http://first.wpi.edu/FRC/roborio/maven/release/edu/wpi/first/wpilib/wpiutil/1.0.2/wpiutil.1.02-armhf.zip

          into ../cscore/arm/build/dependencies
        - change name in ../cscore/arm/build/dependencies

          mv wpiutil-1.0.2-armhf.zip wpiutil.zip
        - edit ../cscore/dependencies.gradle

          comment out line 18: // def wpiUtilConfig ...

          comment out line 19: // wpiUtilConfig.setTransitive(false) ...

          change line 20 to: wpiUtil = 'wpiutil.zip'
    - recompile with: gradlew :arm:build -PtoolChainPath=/usr/local/gcc-linaro-arm-linux-gnueabihf-4.9-2014.09_linux/bin -PcompilerPrefix=arm-linux-gnueabihf- -ParmSuffix=hf
        - build now succeeds and generates the following files

          ./arm/build/libs/cscore/shared/libcscore.so

          ./arm/build/wpiutil/Linux/arm/libwpiutil.so

          ./arm/build/opencv/linux-armhf/libopencv.so

          ./arm/build/opencv/linux-armhf/libopencv_java310.so
- copy over libs to Jetson and test with ldd
    - on Jetson: $ mkdir ~/Downloads/xcompiled
    - on Ubuntu 14 host

> scp arm/build/libs/cscore/shared/libcscore.so ubuntu@tegra-ubuntu.local:Downloads/xcompiled

> scp rm/build/wpiutil/Linux/arm/libwpiutil.so ubuntu@tegra-ubuntu.local:Downloads/xcompiled

- On Jetson, test lib links using ldd

  $ cd Downloads/xcompiled

  $ ldd libcscore.so

  - generates the following error:

    libstdc++.so.6: version `GLIBCXX_3.4.21' not found

- Install 4.9 C++ libraries on Jetson
  - created a tar file of 4.9 C++ libraries on Ubuntu 14 host
    - tar -xf gcc-linaro-arm-linux-gnueabihf-4.9-2014.09_linux.tar.xz
    - cd gcc-linaro-arm-linux-gnueabihf-4.9-2014.09_linux/arm-linux-gnueabihf
    - tar -cf ~/Downloads/armlibs.tar lib
- scp armlibs.tar to Jetson
  - scp armlibs.tar ubuntu@tegra-ubuntu.local:Downloads
- untar libraries on Jetson into /usr/local/lib
  - sudo tar -xf armlibs.tar -D /usr/local
    - /usr/local/lib should now contain libstdc++.so.6.0.20 etc.
- “ldd libcscore.so” now doesn't print the ibstdc++.so.6: version error

3. Plan C: Install precompiled cscore library artifact from wpilib Maven repository

- On Jetson, download Maven cscore-1.0.2-armhf.zip artifact from http://first.wpi.edu/FRC/roborio/maven/release/edu/wpi/cscore/cpp/cscore/1.0.2/

  to ~/Downloads
- untar to ~/Downloads/cscore-1.0.2-armhf
- sudo mv cscore-1.0.2-armhf/Linux/arm /usr/local/lib
- sudo mkdir /usr/local/include/cscore

- sudo mv cscore-1.0.2-armhf/include/* /usr/local/include/cscore
- note: this option leads to a run time core dump if CameraServer.GetInstance() is called

OpenCV (3.0)

GRIP 2017 requires features from OpenCV 3.0 or greater (at least libopencv_videoio.so) so the CV4Tegra version installed in /lib can't be used (get linker errors). Instead a later version (3.0) will be built from source

1. Reference: http://elinux.org/Jetson/Installing_OpenCV
2. get source
   - git clone https://github.com/opencv/opencv.git
   - cd ~/opencv
3. checkout version 3.0.0
   - git checkout tags/3.0.0. -b 3.0.0
4. generate Makefiles using cmake
   - mkdir build && cd build
   - cmake -DWITH_CUDA=ON -DCUDA_ARCH_BIN="3.2" -DCUDA_ARCH_PTX="" -DBUILD_TESTS=OFF -DBUILD_PERF_TESTS=OFF ..
5. build
   - make -j4
6. install
   - sudo make install

CameraServer

1. Get source from MentorRepository
   - copy over Makefile and source code From Ubuntu host
   - $ cd CameraServer
2. build & install
   - $ make
   - $ sudo cp libCameraServer.so /usr/local/lib
   - $ sudo cp CameraServer.h CameraServer.inc /usr/local/include

ImageProc

1. Get source from MentorRepository
   - copy over Makefile and source code From Ubuntu host
   - $ cd Imageproc
2. build
   - $ make

Jetson TX2

System Setup

Hardware

- Jetson TX2 Development kit
  - NVIDIA: $300 (½ price with with Educational discount)
- Optional hardware
  - Acer 22” HDMI capable monitor
    - $99 BestBuy
    - note: VisionWorks demos wont run over VNC or when board is connected via VGA or DVI adapter to a non HDMA monitor
  - Logitech wireless USB keyboard
    - $22 BestBuy
  - Logitech USB mouse
- Cables etc.
  - AC Power Adapter
  - Ethernet cable (to switch)
  - USB to micro-USB cable (needed for os flashing)
  - USB hub (to connect keyboard and mouse)

Software

- Packages installed via Jetpack 3.0

    - includes cuda 8.0, cudnn 5.1
    - Ubuntu 16.04 OS
        - uname -a: Linux tegra-ubuntu 4.4.15-tegra #1 SMP PREEMPT Wed Mar 1 21:09:29 PST 2017 aarch64 aarch64 aarch64 GNU/Linux
    - Optional installs
        - VisionWorks
        - OpenCV4Tegra (2.4 variant)
        - NVIDIA-samples
- Ubuntu Tweaks
    - Installed “Flashback” to replace Unity desktop
- OpenCV (3.2)
    - build and install instructions can be found here:
        - http://www.jetsonhacks.com/2017/04/05/build-opencv-nvidia-jetson-tx2/
- ntcore,cscore,CameraServer
    - These FRC libraries were built natively on the TX2 similarly to that described above for the NVIDIA TK1
- YOLO, SSD
    - “Deep Learning” processing libraries
    - downloaded from git repositories and built natively
        - YOLO:https://github.com/pjreddie/darknet
        - SSD: https://github.com/weiliu89/caffe/tree/ssd

Object Detection Using “Deep learning”

In this context “Object Detection” is defined as the capability to identify specific objects in camera images and to find bounding boxes that encompass them. “Deep Learning” refers to the use of an advanced machine leaning technique that employs so-called “Artificial Neural Networks” (ANNs)

Motivation

In past years challenges (2016, 2017) “object detection” for robot targeting was successfully carried out by our team using relatively simple image processing libraries (NIVision, GRIP). These methods can be used to identify features in image data based on special color properties of the targets which are typically marked with retro-reflective tape and illuminated by a bright light source.

Color segmentation by hue only can be very fast, particularly if an optimized library such as OpenCV is used and allows for real-time targeting without the need for special vision processing hardware (i.e. it can run on the RoboRio). On the negative side these methods suffer from the following limitations:

1. Tuning the camera and image processing software to only detect the object of interest (usually a simple tape pattern) can be tricky
   - In practice it's not sufficient to simply find regions in the image that are of the correct color but to also use geometry constraints (e.g. height to width ratios) to further isolate the desired targets from background lighting artifacts, reflections etc.
2. Differences in background lighting on the various FRC practice and competition fields can render the technique useless unless recalibration is carried out at the start of each match
3. Reflections of the light ring used to illuminate the reflective tape can be confused with targets
   - This was a major problem for us in the 2017 game because the tape pattern surrounding the gear spike target was placed on a reflective plastic surface on the competition field (but not on the test apparatus in the practice fields, which were backed with plywood)
4. In some situations (e.g. the 2017 game) the target pattern of interest may look different depending on the angle of view and distance the from the camera
   - e.g. at a sufficiently large offset angle the spike at the center of the gear placement target split one of the two bordering tape rectangle into 2 halves (resulting in 3 rectangles vs 2)
5. Target detection by color alone is probably not feasible at all unless the targets are marked with reflective tape or have a very unique color
   - e.g. the method could not be used to detect the gray balls (aka “boulders”) on the field in the 2016 game

Objectives

1. Train an artificial neural network to recognize target objects in a simulated FRC field
2. Use the trained ANN to track objects in real time and pass targeting information to the robot program (FRCUserprogram) running on the host computer
3. Generate a visual display of targets (with bounding boxes) in “SmartDashboard”
4. Use the real-time object detection feedback loop to control targeting in Autonomous mode

Implementation

1. The best state-of-the-art techniques that can be used for real-time object detection are too

computationally expensive to run on even multi-core ARM based hardware (e.g. RoboRio, Raspberry Pi3) and require at least a minimally capable graphics card (GPU) such as that provided by an NVIDIA Tx1 or Tx2

- adequate "real time" performance is assumed to be at least 5 frames a second processing speed with less than a half second of absolute latency

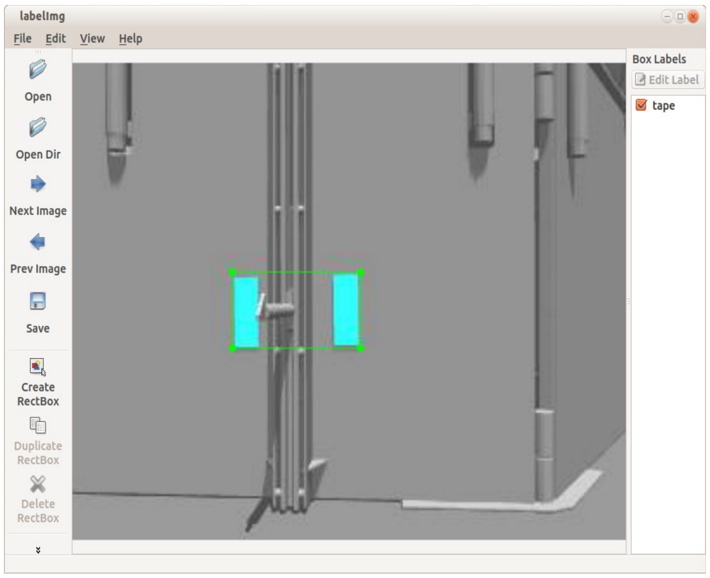
2. Two ANN technologies that can be used for real-time object detection on these "modest" GPU based hardware platforms include :

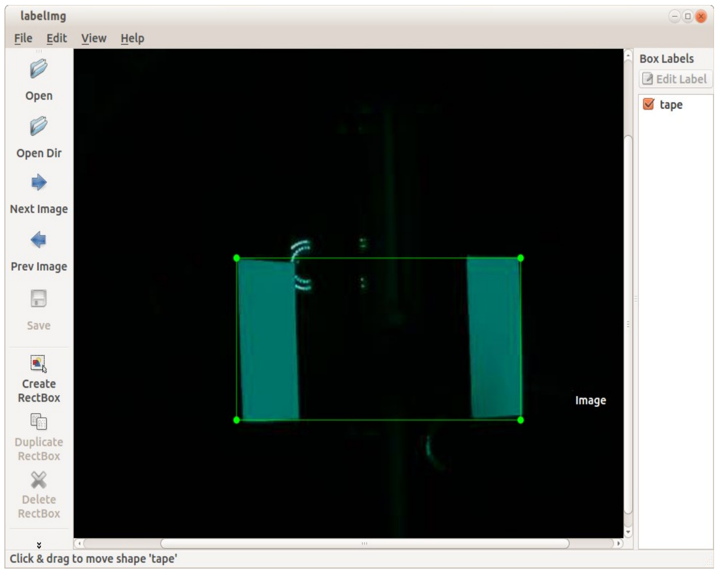
- SSD ("Single-Shot multi-box Detection")
- YOLO ("You Only Look Once" or "darknet")
- Both of these methods were implemented on the NVIDIA Tx2 platform and exhibited similar performance (YOLO was somewhat faster but the bounding boxes generated by SSD were more accurate)
    - SSD was also implemented on the older, less capable NVIDIA Tk1 GPU and was found to run too slow (~1.3 FPS) to be acceptable for RT control
- Further details on these methods can be found in the AdvancedAITools document described previously

3. Training details

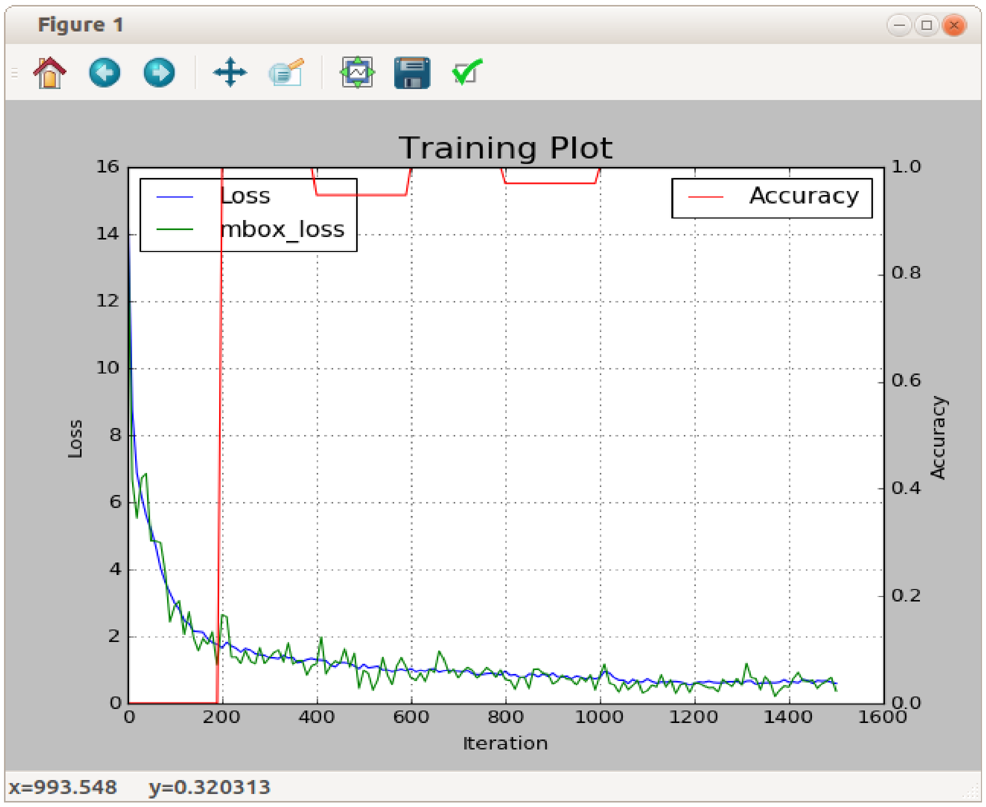
- Both SSD and YOLO require training data where bounding boxes are hand drawn around targets in a set of images
- A python based graphics tool called "LabelImg" (https://github.com/tzutalin/labelImg) was used to annotate the images and save the bounding box information in an xml file format

- Raw images were obtained by driving a model robot with a simulated camera around in a (simulated) FRC field that contains targets relevant to past games
    - In one test case "totes" and "balls" were placed in a simulated 2015 "recycle rush" field
    - in another the annotated targets were "gears" and "spikes" were placed in the 2017 Gazebo "Steamworks" field
        - This later image set also included a set of images of spike patterns obtained from an actual FRC field under dim lighting conditions (e.g. see right image below)



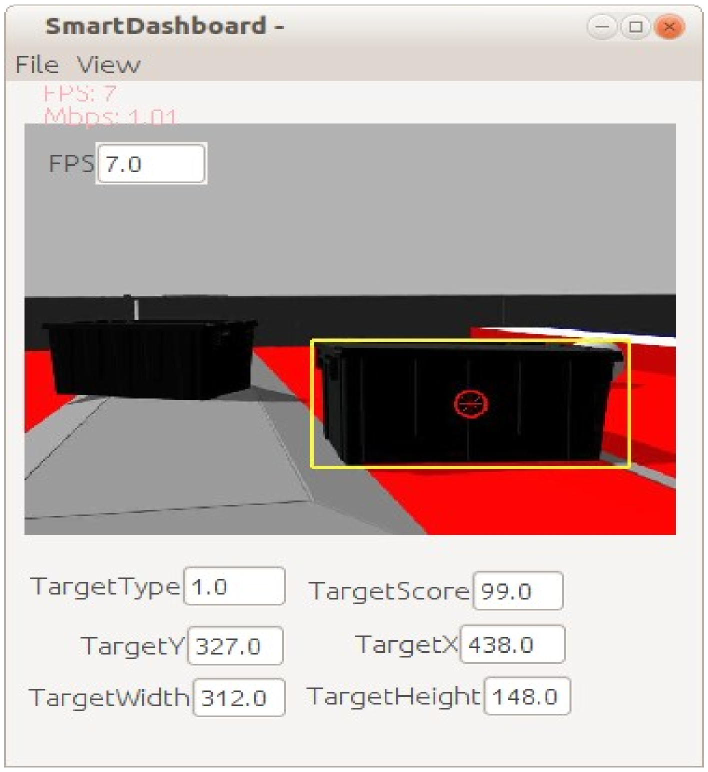


- Training was carried out on a Linux Desktop that contained a high end GPU (a NVIDIA GTX 980 with 2048 cores)
  - training typically required 1-2 hours
  - a typical training curve (SSD)



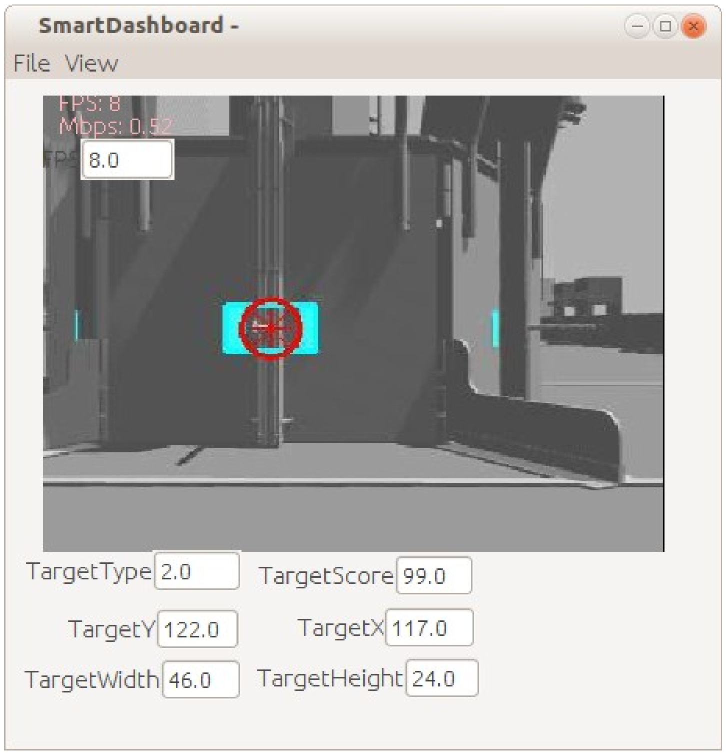
Results

1. Performance measurements
   - SSD
     - 300x300 image size
       - 7-8 FPS
       - box quality: very good
   - YOLO
     - "tiny" YOLO
       - 32 FPS processing
       - box quality: poor
     - 300x300 image size:
       - 12 FPS
       - box quality good
2. SmartDashboard interface examples (SSD)



FPS 7.0

TargetType 1.0 TargetScore 99.0
TargetY 327.0 TargetX 438.0
TargetWidth 312.0 TargetHeight 148.0



FPS 8.0

TargetType 2.0 TargetScore 99.0
TargetY 122.0 TargetX 117.0
TargetWidth 46.0 TargetHeight 24.0

    -

3. Autonomous mode test
   - goal: Place gear on spike from center position in 2017 simulated field
   - result: percentage of times gear was successfully placed on the spike was similar to that observed when the image processing was done using GRIP (>50%)
     - note: the main problem with consistency was not the image processing loop but rather the fact that that there was no way to place the gear in a reproducible position on the holding plate or to observe where the spike was located WRT the gear at close distances due to the offset camera position
4. Conclusions
   - The NVIDIA TX2 running deep learning algorithms has provide sufficient processing power to identify and locate arbitrary targets in a simulated FRC field

<u>Raspberry Pi-3</u>

Setup

1. Hardware version
   - Raspberry Pi 3 (model B)
   - purchased from NewEgg ($35)
2. Software version
   - Raspbian Jessie-Lite
3. Cables & other hardware
   - micro SD Card reader
   - micro SD card
     - started with a 4G card but ran out of room when installing OpenCV so got a 16 G card
     - recommend 16G or greater
   - USB –> micro USB cable
   - Standard Ethernet cable

Installation of Operating system (from Ubuntu host)

1. Download Raspbian Jessie Lite OS

- source: https://www.raspberrypi.org/downloads/raspbian/
- download file: 2016-05-27-raspbian-jessie-lite.zip
- $ unzip 2016-05-27-raspbian-jessie-lite.zip
- creates: 2016-05-27-raspbian-jessie-lite.img (size:1387266048)

2. Install OS on SD card
   - Instructions: https://www.raspberrypi.org/documentation/installation/installing-images/linux.md
   - Determine the partition number for the SD card reader
     - Remove the SD card reader
     - $ df -h (note: the base configuration info)
     - Insert the SD Card reader with micro Sd card installed
     - $ df -h
     - These are the new devices which appear over the base configuration

       ```
       /dev/sdc1       818M  5.7M  812M   1% /media/dean/D8DE-D3EE
       /dev/sdc2       976M  135M  791M  15% /media/dean/ecabb50d-36f7-4ec3-b449-11c76e8467f5
       ```
     - The full partition for the card is therefore “sdc” (following the instructions in the ref)
       - note: when this procedure was repeated using a 16G card the partition was “sdg” instead
3. Burn the image onto the SD card
   - $ umount /dev/sdc1
   - $ umount /dev/sdc2 (if present)
   - $ sudo dd bs=4M if=2016-05-27-raspbian-jessie-lite.img of=/dev/sdc
   - $ sync
4. Check validity of image on card (optional)
   - $ sudo dd bs=4M if=/dev/sdc of=from-sd-card.img
     - ls -l: -rw-r--r-- 1 root root 3980394496 Jun 3 09:35 from-sd-card.img

- $ sudo truncate --reference 2016-05-27-raspbian-jessie-lite.img from-sd-card.img
    - ls -l: -rw-r--r-- 1 root root 1387266048 Jun 3 09:37 from-sd-card.img
- $ diff -s 2016-05-27-raspbian-jessie-lite.img from-sd-card.img
    - output: Files 2016-05-27-raspbian-jessie-lite.img and from-sd-card.img are identical

5. Connect up the raspberry Pi
    - Insert micro SD card in slot underneath Pi card
    - connect Ethernet cable from Pi to Host (or switch)
    - Connect USB power cable from Pi to USB port on host
        - The board should now boot the OS
6. Test connection from Host to Pi
    - $ ping raspberrypi.local
        - should get responses
    - $ ssh -l pi raspberrypi.local
        - enter “raspberry” as password
        - Should see command prompt: pi@raspberrypi:~ $
7. Configure Pi so that a password isn't required on login

    On Localhost:
    - `$ ssh-keygen`
        - `enter a passphase`
    - `$ cat ~/.ssh/id_*.pub | ssh pi@raspberrypi.local 'cat > .ssh/authorized_keys'`
        - `note: first make sure that Pi already has a .ssh directory`
    - $ ssh -p pi@raspberry.local
        - On first access a dialog asks for passphrase (use same as entered in ssh-keygen)
        - On subsequent logins passphase isn't required

OpenCV

1. Version
    - 3.0 (or 3.1)

2. Reference

   - http://www.pyimagesearch.com/2015/10/26/how-to-install-opencv-3-on-raspbian-jessie/

3. Install dependent libraries

   - Log onto Pi `(ssh -l pi raspberrypi.local)`
   - From reference instructions
     - pi@raspberrypi:~ sudo apt-get update
     - pi@raspberrypi:~ sudo apt-get upgrade
     - pi@raspberrypi:~ sudo rpi-update
     - pi@raspberrypi:~ sudo reboot
     - pi@raspberrypi:~ sudo apt-get install libjpeg-dev libtiff5-dev libjasper-dev libpng12-dev
     - pi@raspberrypi:~ sudo apt-get install libavcodec-dev libavformat-dev libswscale-dev libv4l-dev
     - pi@raspberrypi:~ sudo apt-get install libxvidcore-dev libx264-dev
     - pi@raspberrypi:~ sudo apt-get install libatlas-base-dev gfortran
     - pi@raspberrypi:~ sudo apt-get install python2.7-dev python3-dev
     - pi@raspberrypi:~ sudo apt-get install libgtk2.0-dev (do we need this for headless processing ?)

4. Obtain opencv source

   (This procedure differs from reference instructions which uses a tar file)

   - Log onto Pi
   - pi@raspberrypi:~ git clone https://github.com/Itseez/opencv.git
   - pi@raspberrypi:~ cd opencv
   - pi@raspberrypi:~ git checkout tags/3.0.0 -b 3.0.0
     - note: for 3.1 version use: :~ git checkout tags/3.1.0 -b 3.1.0

5. Setup Python (2.7)

   - pi@raspberrypi:~ wget https://bootstrap.pypa.io/get-pip.py
   - pi@raspberrypi:~ sudo python get-pip.py
   - pi@raspberrypi:~ sudo pip install virtualenv virtualenvwrapper

- pi@raspberrypi:~ sudo rm -rf ~/.cache/pip
- added to bottom of ~/.profile

  export WORKON_HOME=$HOME/.virtualenvs
  source /usr/local/bin/virtualenvwrapper.sh
- pi@raspberrypi:~ source ~/.profile
- pi@raspberrypi:~ mkvirtualenv cv
  - command prompt should now be: (cv)pi@raspberrypi~
  - note: after rebooting etc. to get back into the "cv environment" enter "workon cv" (ctrl-d to exit)
- (cv)pi@raspberrypi:~ pip install numpy
  - takes about 15-20 minutes to complete

6. Build opencv
   - (cv)pi@raspberrypi:~ mkdir release && cd release
   - (cv)pi@raspberrypi:~ ccmake ..
     - kept most defaults except turned off CUDA and enabled openMP
   - (cv)pi@raspberrypi:~ make -j4
     - took ~1hr to build
     - note: after build disk usage increased from 49->93% on 4G SD card -(need bigger card)
       - So purchased a 16G uSD card ($11) and repeated everything up to this point
       - df now shows 25% usage
7. Finishing the installation
   - (cv)pi@raspberrypi:~ cd ~/.virtualenvs/cv/lib/python2.7/site-packages/
   - (cv)pi@raspberrypi:~ ln -s /usr/local/lib/python2.7/site-packages/cv2.so cv2.so
8. Verify installation
   - (cv)pi@raspberrypi:~ python

     >>> import cv2

     >>> cv2.__version__

     '3.0.0'

```
>>>
```

- Use Ctrl-d to exit Python

9. Python Utility functions

- Display image data sent from Pi in host window

```
#!/usr/bin/python
# run on Ubuntu host
# opens a window and updates whenever a new image is sent from client

import socket
import cv2
import numpy

def recvall(sock, count):
    buf = b''
    while count:
        newbuf = sock.recv(count)
        if not newbuf: return None
        buf += newbuf
        count -= len(newbuf)
    return buf

TCP_IP = 'Ubuntu14.local' # DHCP hostname or static ip of host
TCP_PORT = 5001

s = socket.socket(socket.AF_INET, socket.SOCK_STREAM)
s.bind((TCP_IP, TCP_PORT))
s.listen(True)
cv2.namedWindow("SERVER")
while True:
  conn, addr = s.accept()
  length = recvall(conn,16)
  stringData = recvall(conn, int(length))
  data = numpy.fromstring(stringData, dtype='uint8')
  decimg=cv2.imdecode(data,1)
  cv2.imshow('SERVER',decimg)
  if cv2.waitKey(25) == 27:
    break
s.close()
cv2.destroyAllWindows()
```

- Send opencv image (captured from USB camera)to Host for display

```
#!/usr/bin/python
# runs on Pi
import socket
import cv2
import numpy

TCP_IP = 'Ubuntu14.local' # DHCP hostname or static ip of host
TCP_PORT = 5001

sock = socket.socket()
```

```
sock.connect((TCP_IP, TCP_PORT))

capture = cv2.VideoCapture(0)
ret, frame = capture.read()

encode_param=[int(cv2.IMWRITE_JPEG_QUALITY),90]
result, imgencode = cv2.imencode('.jpg', frame, encode_param)
data = numpy.array(imgencode)
stringData = data.tostring()

sock.send( str(len(stringData)).ljust(16));
sock.send( stringData );
sock.close()
cv2.waitKey(0)
```

GRIP 2016 (Java Deploy)

1. Reference
   - https://github.com/WPIRoboticsProjects/GRIP/wiki/Running-GRIP-on-a-Raspberry-Pi-2
2. Obtain required library files by pressing the links in the above reference
   - libntcore.so,libstdc++.so.6
3. Download system libraries
   - Create destination directory on pi
     - log onto Pi (ssh -l pi raspberrypi.local)
     - pi@raspberrypi:~ mkdir vision
     - pi@raspberrypi:~ cd vision
     - pi@raspberrypi:~ mkdir grip
   - Install Java 8 on Pi
     - pi@raspberrypi:~ sudo apt-get update && sudo apt-get install oracle-java8-jdk
   - scp libraries from Host to Pi (in a separate Host command shell)
     - $ scp libntcore.so pi@raspberrypi.local:/home/pi/vision/grip/libntcore.so
     - $ scp libstdc++.so.6 pi@raspberrypi.local:/home/pi/vision/grip/libstdc++.so.6
4. Build and Install **mpeg-streamer** to fix reported bug with running USB cameras on Pi
   - Obtain libraries and source code
     - Log onto Pi (ssh -l pi raspberrypi.local)

    - pi@raspberrypi:~ sudo apt-get update && sudo apt-get install git
    - pi@raspberrypi:~ sudo apt-get update && sudo apt-get install cmake
    - pi@raspberrypi:~ sudo apt-get update && sudo apt-get install libjpeg8-dev
    - pi@raspberrypi:~ cd vision
    - pi@raspberrypi:~ git clone https://github.com/jacksonliam/mjpg-streamer.git
- Build from source and install
    - pi@raspberrypi:~ cd mjpg-streamer/mjpg-streamer-experimental
    - pi@raspberrypi:~ make clean all
    - pi@raspberrypi:~ sudo make install
- Test USB Camera connection
    - Connect USB camera to one of 4 USB slots on Pi
    - should see “video0” when camera is connected
- Run mpeg-streamer from a command line to test
    - pi@raspberrypi:~ mjpg_streamer -o "output_http.so -w ./www -p 1180" -i "input_uvc.so -d /dev/video0 -f 15 -r 640x480 -y -n"

      Output:

      ```
      MJPG Streamer Version.: 2.0
      i: Using V4L2 device.: /dev/video0
      ..
      ```
    - View Stream from web browser
        - Open a tab in Firefox and enter the following URL: http://raspberrypi.local:1180/?action=stream
        - Should see an image from the camera in the tab
    - View Stream on host using a Python script
        - file stream-server.py:

      ```
      #!/usr/bin/python
      import cv2
      import urllib
      ```

```
import numpy as np
stream=urllib.urlopen('http://raspberrypi.local:1180/?action=stream')
bytes=''
while True:
    bytes+=stream.read(1024)
    a = bytes.find('\xff\xd8')
    b = bytes.find('\xff\xd9')
    if a!=-1 and b!=-1:
        jpg = bytes[a:b+2]
        bytes= bytes[b+2:]
        i = cv2.imdecode(np.fromstring(jpg,dtype=np.uint8),cv2.CV_LOAD_IMAGE_COLOR)
        cv2.imshow('camera',i)
        if cv2.waitKey(1) == 27:
            exit(0)
```

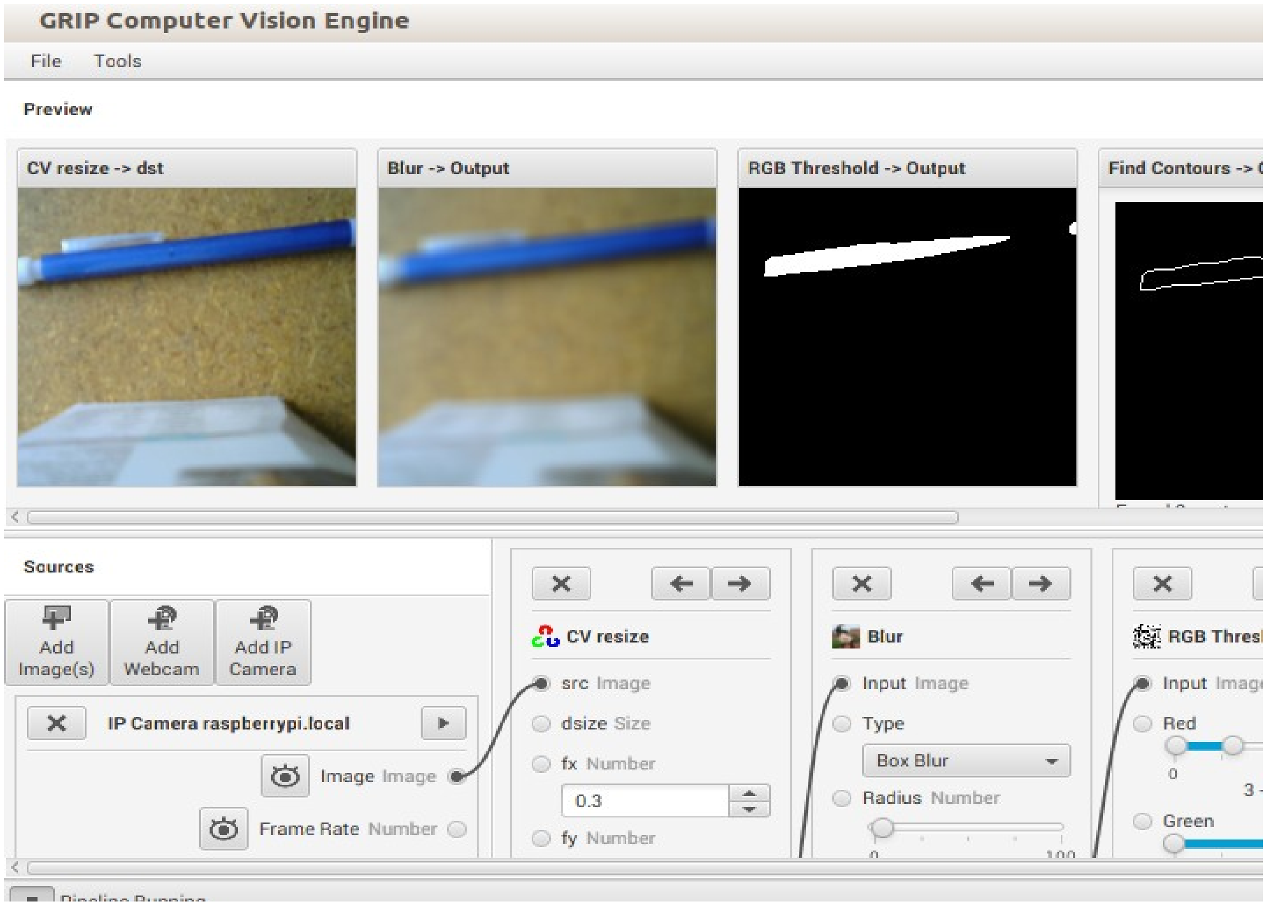
- On Pi, start mpeg-streamer
- On Host, $ python stream-server.py

5. Test Image stream from Pi running GRIP on host

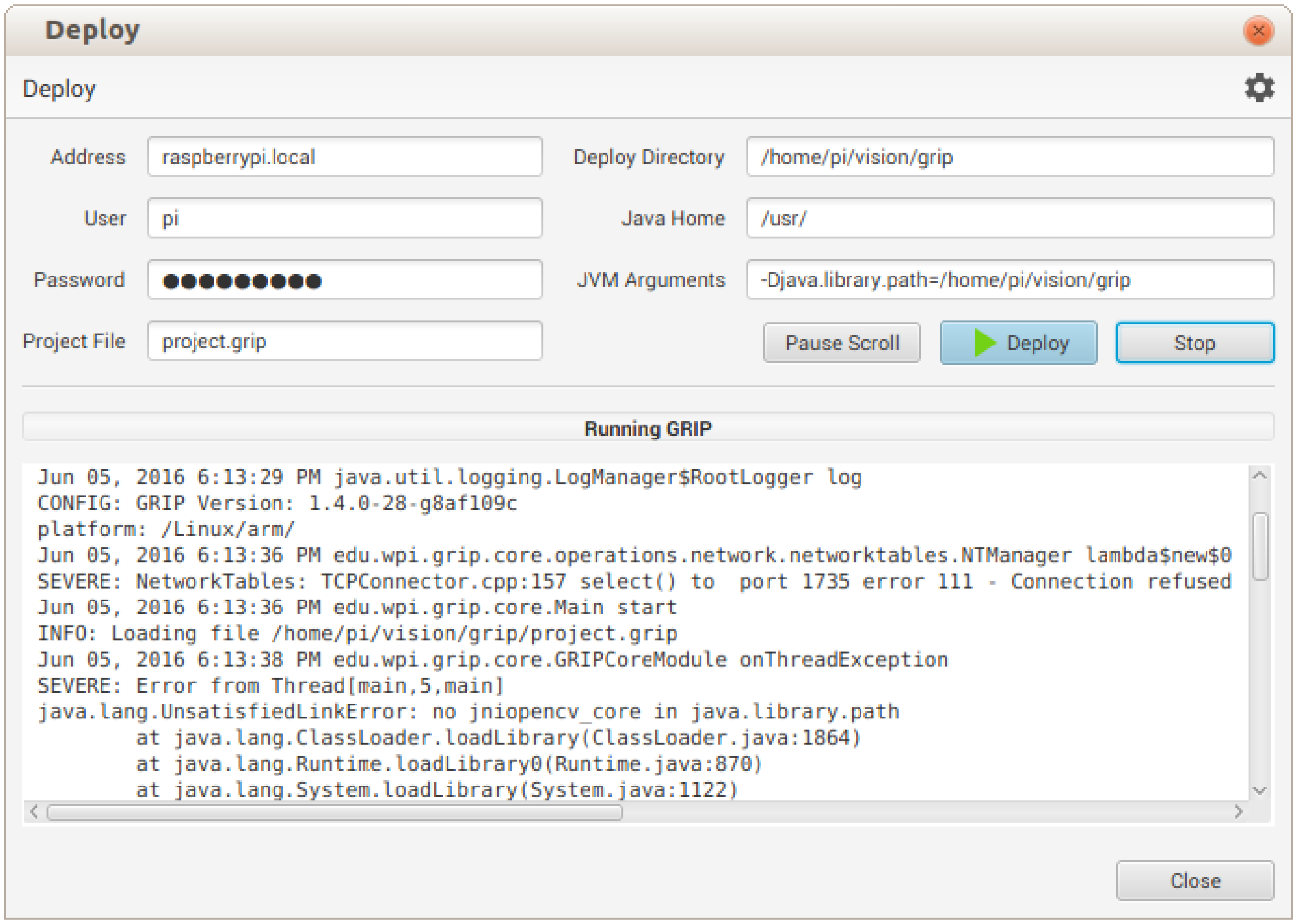
   On Pi start up mpeg streamer as described in the previous section

   - `pi@raspberrypi:~ mjpg_streamer -o "output_http.so -w ./www -p 1180" -i "input_uvc.so -d /dev/video0 -f 15 -r 640x480 -y -n"`

- On Host, start up GRIP with project using one of the methods described above
  - ui/build/install/ui/bin/ui projects/webcam-blue/webcam-blue.grip
- In GRIP UI, replace the WebCam input with “Add IP Camera” input
  - Set URL in Ip Camera dialog to: http://raspberrypi.local:1180/?action=stream
- Should see same processing behavior as when USB camera was connected directly to the Host



6. Verify and try to fix USB camera bug on Pi
    - Was able to get normal USB "WebCAM" GRIP input source to work after installing `fswebcam as described in:` https://www.raspberrypi.org/documentation/usage/webcams/
    - Couldn't see images but got ContoursReport updates in ntables
    - When trying to run mpeg-streamer and a headless GRIP project that was using the webcam simultaneously mpeg-streamer aborted with "illegal image format error"
        - mpeg-streamer worked again once GRIP project was killed
7. Deploy Host GRIP project on Pi (following instructions in ref)
    - On Host start up GRIP and load project
    - Change Source to IP Camera (URL=http://raspberrypi.local:1180/?action=stream) as described in the previous section
    - Set Deploy options as shown



Address: raspberrypi.local
User: pi
Password: ●●●●●●●●●●
Project File: project.grip
Deploy Directory: /home/pi/vision/grip
Java Home: /usr/
JVM Arguments: -Djava.library.path=/home/pi/vision/grip

```
Jun 05, 2016 6:13:29 PM java.util.logging.LogManager$RootLogger log
CONFIG: GRIP Version: 1.4.0-28-g8af109c
platform: /Linux/arm/
Jun 05, 2016 6:13:36 PM edu.wpi.grip.core.operations.network.networktables.NTManager lambda$new$0
SEVERE: NetworkTables: TCPConnector.cpp:157 select() to  port 1735 error 111 - Connection refused
Jun 05, 2016 6:13:36 PM edu.wpi.grip.core.Main start
INFO: Loading file /home/pi/vision/grip/project.grip
Jun 05, 2016 6:13:38 PM edu.wpi.grip.core.GRIPCoreModule onThreadException
SEVERE: Error from Thread[main,5,main]
java.lang.UnsatisfiedLinkError: no jniopencv_core in java.library.path
        at java.lang.ClassLoader.loadLibrary(ClassLoader.java:1864)
        at java.lang.Runtime.loadLibrary0(Runtime.java:870)
        at java.lang.System.loadLibrary(System.java:1122)
```

- Pressed Deploy button
    - copies grip.jar (1.4.0-28-g8af109c) and project.grip to ~/vision/grip on Pi
    - fails with error: “no jniopencv_core in java.library.path”
        - without -Djava.library.path get unsatisfied link error for ntcore
    - Same problem observed when running from command line logged into pi
    - libjniopencv_core.so etc. appears to be part of javacv (and javacpp)
    - But haven't been able to locate a pre-built binary for raspberry (arm) so will try to build them from source

8. Build javacpp and javacv from source

- reference: http://alltechanalysis.blogspot.com/2015/09/installing-opencv-30-and-javacv-on.html

- pi@raspberrypi:~ cd
- pi@raspberrypi:~ sudo apt-get install maven
- pi@raspberrypi:~ git clone https://github.com/bytedeco/javacpp-presets
- pi@raspberrypi:~ git clone https://github.com/aravindrajasekharan/JavaCpp-OpenCv-Linux-Arm.git
- pi@raspberrypi:~ cd JavaCpp-OpenCv-Linux-Arm
- pi@raspberrypi:~ cp cppbuild.sh ../javacpp-presets/opencv
- pi@raspberrypi:~ cd ../javacpp-presets
- pi@raspberrypi:~ export PLATFORM=linux-arm
    - instruction is missing in reference
- pi@raspberrypi:~ git checkout tags/1.1 -b 1.1
    - instruction is missing in reference
    - compatible with opencv version 3.0
    - note: latest version (1.2) fails to build
- pi@raspberrypi:~ ./cppbuild.sh
    - builds local opencv 3.0 (succeeds)
    - takes ~1/2 hour
- pi@raspberrypi:~ mvn clean install -DskipTests -Dplatform.name=linux-arm
- After ~ 1hour
    - [INFO] JavaCPP Presets .... SUCCESS [45.900s]

      [INFO] JavaCPP Presets for OpenCV .... SUCCESS [48:05.816s]

      [INFO] JavaCPP Presets for FFmpeg .... FAILURE [0.922s]
    - [ERROR] Failed to execute JavaCPP Builder: Could not parse "libavutil/avutil.h": File does not exist
    - But found "libavutil/avutil.h" in several sub-directories
        - e.g. ./opencv/cppbuild/linux-arm/opencv-3.0.0/3rdparty/include/ffmpeg_/libavutil/avutil.h

- However,jni libraries seem to have been built anyway
    - e.g. ./opencv/target/classes/org/bytedeco/javacpp/linux-arm/libjniopencv_core.so exists etc.
- copied /opencv/target/classes/org/bytedeco/javacpp/linux-arm/*.so /usr/lib
- re-ran grip launcher script (start_grip.sh) from ~/vision
    - export LD_LIBRARY_PATH=/home/pi/vision/grip; java -jar /home/pi/vision/grip/grip.jar /home/pi/vision/projects/project.grip &
    - no longer get "no jniopencv_core in java.library.path"
    - but now get the following errors
        - SEVERE: The CV resize operation did not perform correctly.

          java.lang.RuntimeException: /home/pi/javacpp-presets/opencv/cppbuild/linux-arm/opencv-3.0.0/modules/imgproc/src/imgwarp.cpp:3208: error: (-215) ssize.area() > 0 in function resize

          several of these then ..
        - Jun 09, 2016 3:45:09 AM edu.wpi.grip.core.Main onExceptionClearedEvent

          INFO: Exception Cleared Event

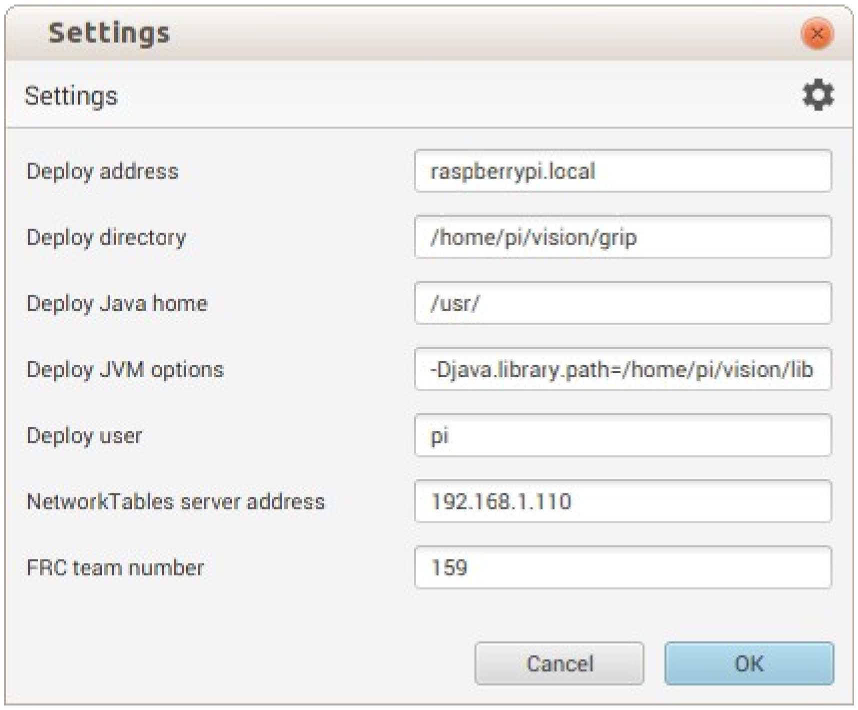
          Jun 09, 2016 3:45:09 AM edu.wpi.grip.core.operations.network.networktables.NTManager lambda$new$0

          SEVERE: NetworkTables: TCPConnector.cpp:157 select() to 127.0.0.1 port 1735 error 111 - Connection refused

          this error keeps repeating until process is killed
- Got "Deploy" in host grip GUI to run (but generate similar errors) by changing JVM Arguments to:

  -Djava.library.path=/home/pi/vision/grip:/usr/lib
    - note: missing jni libraries are now in /usr/lib
- Fix for "connection refused" error
    - On Pi modified project.grip file to change ip of "PublishAddress" element to that of Linux host (as determined by ifconfig)
    - started Network Tables server on host

    - started mpeg-streamer on Pi
    - started start_grip.sh on Pi
    - Now, no longer get connection refused errors but Network Tables GUI shows invalid data in fields “[]”
    - problem was that blue pencil was missing from camera view
    - Repositioned pencil and now see values being updated in Network Tables window !
- Set PublishAddress from GRIP GUI
    - Open “settings” dialog and change “Network Tables Server Address to ip of Host (i.e as



Settings

Settings

Deploy address	raspberrypi.local
Deploy directory	/home/pi/vision/grip
Deploy Java home	/usr/
Deploy JVM options	-Djava.library.path=/home/pi/vision/lib
Deploy user	pi
NetworkTables server address	192.168.1.110
FRC team number	159

determined by running ifconfig)

    - Can then directly deploy the GRIP project to Pi without needing to hand-edit the project.grip file
    - When the “Deploy” button is pressed network tables are updated by the “headless” GRIP project running on the Pi and the image “pipeline” to the UI GRIP running on the host is stopped
    - After stopping the headless GRIP project from the “Deploy” dialog window press the small button labled “Pipeline Stopped” in the lower-left corner of the GRIP interface to resume processing from the UI Grip application

GRIP 2017 (OpenCV application)

In the section, implementation notes for deployment on a raspberry PI 3 will be described

References

- http://www.gurucoding.com/en/raspberry_pi_eclipse/configuring_raspberry_pi.php
- http://wpilib.screenstepslive.com/s/4485/m/24194/l/682949-vision-processing-on-an-arm-coprocessor

cscore

Contains wpi camera support libraries and header files as a wrapper class for native OpenCV functions

- A version compiled for raspian jessie is available from the following wpi Maven repository: http://first.wpi.edu/FRC/roborio/maven/release/edu/wpi/cscore/cpp/cscore/1.0.1/cscore-1.0.1-arm-raspbian.zip
- Installation (from Windows)
  1. log onto raspberry pi
     - Open up a GitBash window and log onto raspberry
     - $ ssh pi@raspberrypi.local (password=raspberry)
  2. use wget to download zip file
     - $ wget <zip file link given above>
     - $ unzip 1.0.1-arm-raspbian.zip
       - unzips to include and Linux directories
  3. Install libraries and headers
     - $ sudo mv Linux/arm/* /usr/lib
     - $ sudo mkdir /usr/local/include/cscore
     - $ sudo mv include/* /usr/local/include/cscore
  4. Test installation
     - Obtain prebuilt camera test application
       - $ wget http://first.wpi.edu/FRC/roborio/coprocessors/ArtifactDetect.zip
       - $ unzip ArtifactDetect.zip

- $ cd ArtifactDetect
- $ chmod +x detect-raspbian
- $ ./detect-raspbian
- part of output:

```
0: /dev/video0 (Logitech, Inc. Webcam C270)
Properties:
CS: usbcam: Connecting to USB camera on /dev/video0
 raw_brightness (int): value=128 min=0 max=255 step=1 default=-8193
 brightness (int): value=50 min=0 max=100 step=1 default=-3212
            ...
```

- Connect a USB camera to the raspberry
- Run the test application

ntcore

The version of libntcore.so that was distributed in 2016 doesn't seem to be compatible with the newer 2017 WPI code (get std::String errors) but building the library from source on the Pi appears to work

1. References
   - https://www.chiefdelphi.com/forums/showthread.php?p=1637299
2. Obtain Source
   - log onto Pi (ssh -l pi raspberrypi.local)
   - pi@raspberrypi: git clone https://github.com/wpilibsuite/ntcore
   - pi@raspberrypi: cd ntcore
3. Build using cmake
   - pi@raspberrypi: export JAVA_HOME=/usr/lib/jvm/jdk-8-oracle-arm32-vfp-hflt
     - without this cmake fails
   - pi@raspberrypi: mkdir build && cd build
   - pi@raspberrypi: cmake ..
4. install
   - pi@raspberrypi: sudo make install

CameraServer

Can be built from source either from Ubuntu/Windows development system using Eclipse with an ARM Cross-complier or directly on the PI using a makefile

Cross-Compiler method(see next section for setup):

- Open CameraServer project in MentorRepository
- Create a new build configuration (RPI-CCUbuntu)
- Set toolchain type as cross-compiler
- Set Cross Path : $HOME/rpi/tools/arm-bcm2708/gcc-linaro-arm-linux-gnueabihf-raspbian-x64/bin
- Set Cross Prefix to: arm-linux-gnueabihf-
- Add to c++ include paths
  - /home/dean/rpi/tools/arm-bcm2708/gcc-linaro-arm-linux-gnueabihf-raspbian-x64/arm-linux-gnueabihf/include/c++/4.8.3
  - ${WPILIB}/simulation/include
    - or ${WPILIB}/cpp/current/include ?

Set up ARM Cross-compiler on Eclipse

1. Windows
   - Download and install arm cross-compiler installer for windows
     - http://sysprogs.com/files/gnutoolchains/raspberry/raspberry-gcc4.9.2-r4.exe
2. Ubuntu
   - Download cross compiler toolchain
     - mkdir ~/rpi
     - git clone https://github.com/raspberrypi/tools
3. Build Eclipse Test Application
   - Open a new cross-compile project (e.g. HelloWorldArm)
   - On project setup set path to cross-compiler:
     - e.g. Windows: C:\SysGCC\Raspberry\bin

        - Set compiler prefix:
            - arm-linux-gnueabihf-
        - press Build button (hammer)
            - find the build artifact in Debug directory
    - Test “HelloWorld” test app on the raspberry pi
        - Open a git bash shell and cd to Directory of build artifact
        - copy the application to the raspberry
            - scp HelloWorldArm pi@raspberrypi.local:.
        - run the app on the Raspberry
            - $ chmod +x HelloWorldArm
            - $ ./ HelloWorldArm
            - !!!Hello World!!!

Set up Eclipse for remote access

- followed basic procedure from the following link:
    - http://www.gurucoding.com/en/raspberry_pi_eclipse/raspberry_pi_remote_access_in_eclipse.php
- Notes
    - Didn’t get ssh terminal option in Remote Systems view
        - But could open a terminal by ctrl-alt-shift T while in an Eclipse editor window and add a new remote location
- Compile natively on RP3 from Eclipse on Ubuntu (Alternative to using a cross compiler)
    - Use “Remote Systems Tree” in “Remote System explorer” perspective to copy files between Ubuntu and RP3
        - create mirror project directories (e.g. CameraDerver, ImageProc) on RP3 and copy over source files from Ubuntu
        - Create Makefiles in eclipse and copy to project directories on RP3
    - Build and projects on RP3
        - Open a remote terminal view in Ubuntu Eclipse to RP3
        - cd to RPI project directory

        ▪ run make make install etc.

ImageProc

1. Copy over makefile and source files from MentorRepository and build natively

Robot Image processing Code (2016 game)

Vision interface class

Specifications

1. Front end (API for Robot program) should be the same for whatever back end processing engine is used (e.g. GRIP, ni-vision, native openCV, advanced image recognition tools etc.)
2. Front end API should not be different when compiling for simulation or deploy targets

Front end Interface

1. Configure API with camera and target property information (width, height etc)
    - It may be possible to obtain some camera information automatically
2. Receive target information from back-end in an array of structures or class objects containing:
    - Identity code for each object recognized
    - distance from camera (in feet or meters), left right offset angle, inclination angle (in degrees or radians)

Back end processing

1. Capture net-tables data generated from processing engine (e.g. GRIP)
2. generate target information data structure(s) that contain real world distance and position information etc.
    - Use Configuration information to convert between screen space and real world dimensions

Simulation Tasks

Determine the distance from a target based on the size of the target in an image

1. Distance (inches)=0.866*image_width*target_width/target_image_width;
    - 0.866 = 1/(2*tan(RPD(FOV/2.0))); for FOV = 60 degrees
    - image_width = width of camera image (e.g. 320 pixels)
    - target_image_width = width(pixels)of target in image
    - target_width = assumed physical width of target (inches)
1. for the 2016 tape pattern on a tower, the width of image projection may suffer less distortion (fore-shortening) than the height because of the low angle of view

2. compare distance values calculated from images with those returned using (simulated) lidar sensor
   - Distance values were tested and agreed within ~10%

Determine the shooter angle adjustment based on the vertical position of a target in the image

1. Calculate the vertical error (in degrees) by measuring the displacement of the target center (in pixels) from the midpoint of the image
   - error = 0.5 * image_height - target_centerY * FOV/image_height + v_adjust
     - v_adjust moves the target aiming point up or down from the physical object center
     - For a constant offset
       - v_adjust = 0.886*image_height*target_voffset(inches)/target_distance
     - Generally, v_offset should be calculated based on the expected parabolic trajectory of the ball, distance from the target shooter angle etc.

Determine the robot heading adjustment based on the horizontal position of the target in image

1. Calculate the horizontal error (in degrees) by measuring the displacement of the target center (in pixels) from the horizontal midpoint of the image
2. error = target_centerX+h_adjust-0.5*screen_width
   - h_adjust compensates for fixed lateral displacement of the camera on the robot chassis from the center line of the shooter axis
   - h_adjust = 0.886*screen_width*camera_hoffset/target_distance
   - note: horizontal error is sign-reversed from vertical error

Use image data to reliably place a high goal in Autonomous mode

1. In addition to the Gazebo Robot-2016 field simulation A GRIP project is used to extract target data (width height etc.) from the simulated camera and publish it to a network tables server. The following processes are started up (in the indicated order):
   - mpeg streamer
   - Gazebo Robot-field Simulation
   - sim_ds
   - FRCUserProgram (in linux_simulate)
   - GRIP project
2. Data flow Details
   - The Autonomous command group running in FRCUserProgram first moves the Robot in a

    straight line about ~7 meters though the lowbar and into the opposite courtyard

- The robot is then turned coarsely towards the target on the left side of the tower (~40 degrees) and the shooter is elevated ~20 degrees (way off target but enough to bring the target within the view of the camera)
- The image stream generated by the Gazebo camera is published to the LAN by mjpg-streamer (running on the Ubuntu host)
- The raw images are captured by the GRIP program also running on the Ubuntu host or deployed to the raspberry Pi
- The GRIP program isolates targets in the image stream and publishes their properties to the LAN (as arrays) using the FRC NetworkTables protocol
- The NetworkTables data is captured by the FRCUserProgram (running in Ubuntu) and is made available to the “Image” subsystem class in the Eclipse project

3. In the SimVisionTest Eclipse project a new command “AdjustShot” was created that uses vertical and horizontal offsets in image to center target along shooter axis (by centering target in image)
    - A PID loop is used that maintains the heading to 0 degrees using a simulated gyro
    - Another PID loop is used to stop the robot once the specified distance is reached (using the wheel encoders)

- The NetworkTables data containing the target center and offset data is used by the AdjustShot command to adjust the position of the shooter and robot to move a selected target to the center of the screen
    - Two separate PID loops are used to adjust the horizontal and vertical position of the shooter
        - the horizontal PID adjusts the drive training
        - The vertical PID adjusts the shooter angle
    - the final adjusted shooter angle is ~36 degrees and robot heading ~50 degrees
- When the target is centered ball is shot towards the tower goal

4. Results

- Under “normal” conditions (non-failure modes) a successful goal is scored most of the time (at least 75% ?) using vision assist
    - By contrast, even with the best optimized choices of shooter angle and turn angle a goal

    is scored only about 20% just using dead reckoning

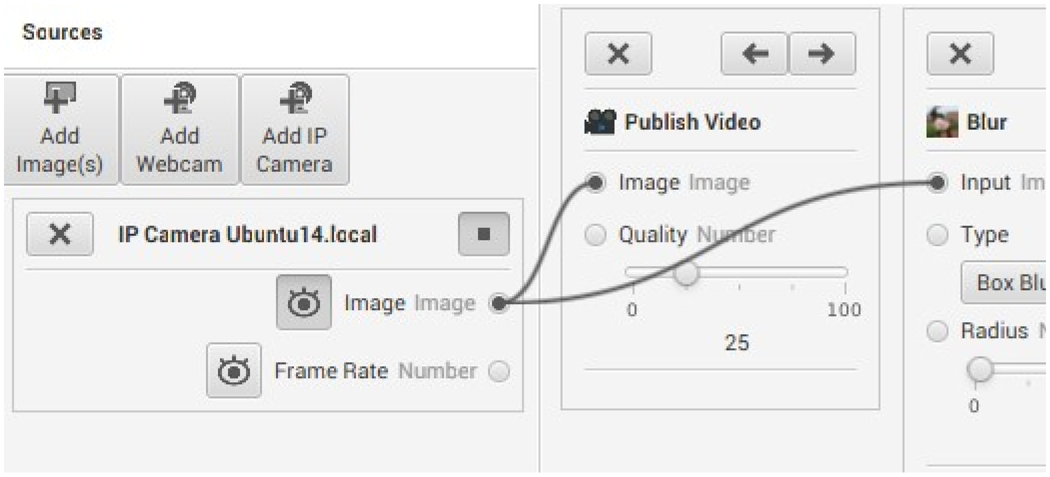
- The GRIP project was also deployed to run on the Raspberry PI
    - Similar behavior was seen with small image size (320x240) . In both cases the shot was usually successful
    - for larger images though (e.g. 640x480) the GRIP project running on the Pi failed to keep up and the correction appeared to oscillate

5. Some observed failure modes:
    - Sometimes the shot is aborted because no ball is detected after targeting
        - When the shooter is raised the ball slips out of the holder gate
            - In the original AdjustShot code the holder push wheel speed wasn't changed while targeting to match the new vertical shooter angle (which was set in the previous StepShooterAngle command)
            - AdjustShot was modified so that the holder push wheel speed was also adjusted while auto-targeting was in progress
    - Sometimes “no targets” are detected even though targets are clearly showing in the net-tables client window and the GRIP UI
        - Since each target attribute (width, centerX etc.) needs to be extracted as a separate call to the NetTables library function it's possible that the data gets corrupted if the tables are updated between one attribute read and the next
        - The “Image” sub-system code was originally designed to exit (reporting 0 targets) if the array size of all attributes aren't exactly the same during a given table read pass
            - Added a modification that captures all the array values first (including array sizes) and instead of reporting “no targets” if all the sizes aren't the same returns the number of targets found in the last “successful” ObtainTargets function call
    - Sometimes during the “AdjustTargets” operation the correction swings too wildly and the camera looses sight of the tower which causes “no targets” to be reported
        - Problem occurs more frequently when GRIP is deployed on the Raspberry Pi
            - In at least one occasion the problem was caused by mjpg-streamer exiting with a failure
            - Problem occurrence lessened by optimizing PID values for Raspberry Pi deployment (using an “#ifdef”)

- Sometimes the shot misses because the robot or shooter report that they are both "on target" (<0.5 degree error) when in fact the error when the shot is taken is actually much larger
    - A Possible reason for this is that the target briefly passes though image center while the PID loops are overshooting (which cause AdjustShot to exit prematurely)
        - Added a modification where two consecutive "on target" results are required to terminate the "AdjustShot" command

Display camera images in SmartDashboard (Java)

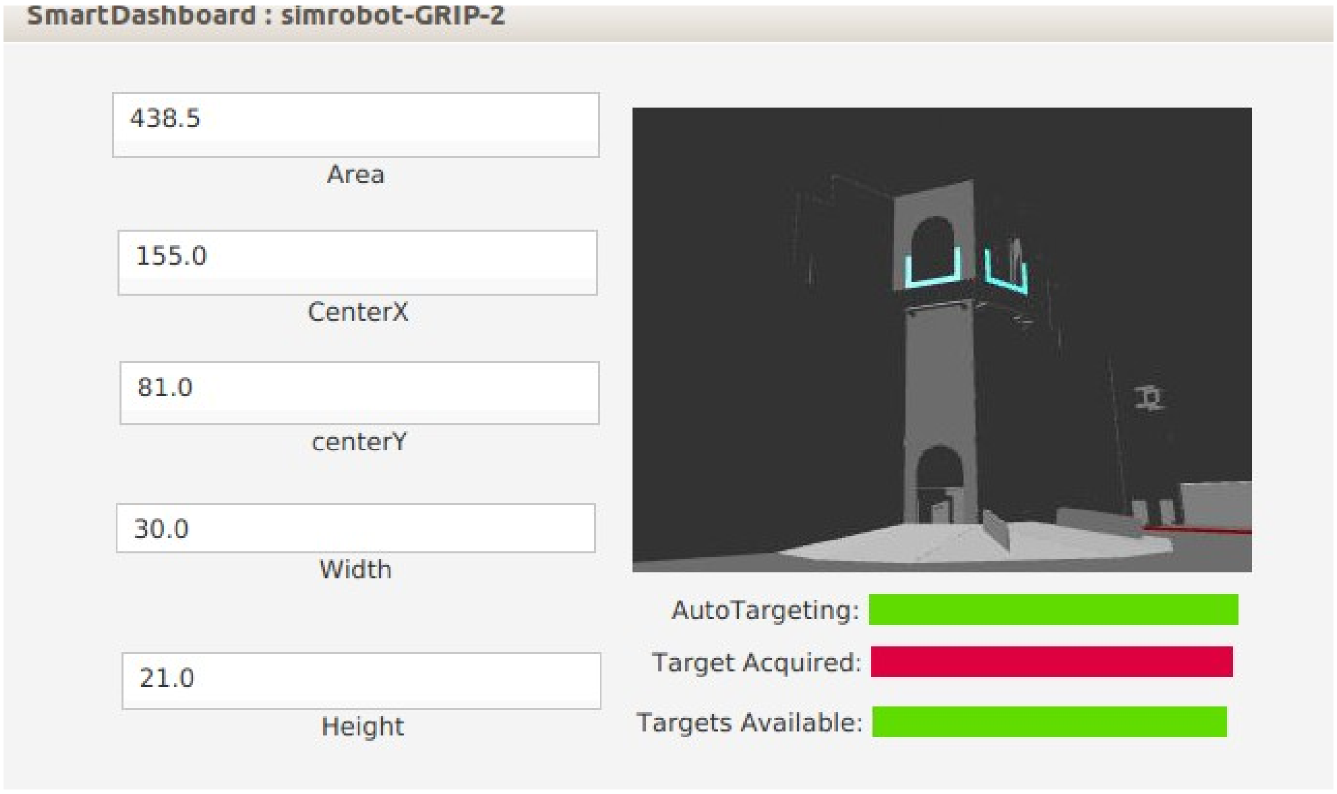
1. Display Camera images images using GRIP Publish video Block
    - There appears to be a plugin at https://github.com/WPIRoboticsProjects/GRIP-SmartDashboard/releases that can display unannotated or annotated images in the older SmartDashboard (not the new JavaFX version)



    - Change the port used by mjpg-server and the GRIP ip camera input from 1180 to 5002
        - SmartDashboard appears to be hard-coded to listen on port 1180 which is also (presumably) the port that the "Publish Video" block in GRIP writes to (though I haven't looked at the code yet)
    - In SD GUI set View->Editable
    - Add a "OutputViewer" to the panel
        - Edit ->Add .. → "GRIP OutputViewer"
        - To change URL right-click in Viewer panel ares and select "properties"
            - Default is URL "localhost" which seems to work for displaying unannoted images
2. Annotate images by drawing bounding boxes around targets

- Problems
    - The target boxes don't always appear and do not follow the camera after the first frame is shown
    - Can only attach "Publish Video" GRIP block to "IP Camera" source
        - e.g. Output of "Blur block" cannot be used as input of "Publish Video" block
        - GUI wont allow a connection to be drawn
- Haven't been able to see images from SmartDashboard running on Windows 10

Display camera images in "SFX" (New JavaFX version)


SmartDashboard : simrobot-GRIP-2

Area	438.5
CenterX	155.0
centerY	81.0
Width	30.0
Height	21.0

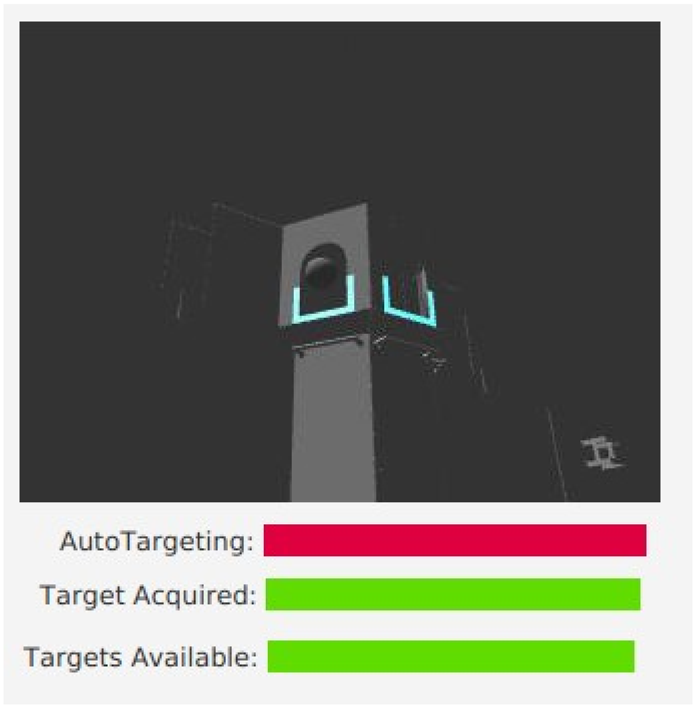
AutoTargeting: 🟩
Target Acquired: 🟥
Targets Available: 🟩

- Add a new Camera object from the "general" list and set it's URL to the video stream being published by mjpg-streamer e.g. : http://Ubuntu14.local:1180/?action=stream
- Problems & Issues:
    - Sometimes there is a very long delay before images start showing up in the Camera Window (or they never appear at all)
    - So far can only see images published from mjpg-streamer (not from the GRIP PublishVideo block)

Support Auto-targeting in Teleop mode

1. Implementation details
    - Added the following functions to “Vision” Subsystem class
        - Set(Get)AutoTargeting
            - Controlled by a joystick button
        - Set(Get)OnTarget
            - Controlled by the auto-targeting system (PID controllers) using target data supplied by GRIP
        - Set(Get)TargetsAvailable
            - Set to true when one or more targets are identified by the GRIP processing system
    - Added “Camera” widget to SmartDashboard 3.0 (SFX) to “GRIP/targets” panel as described in previous sections above
    - Added SmartDashboard “PutBoolean” code to “Vision” subsystem
        - `e.g. SmartDashboard::PutBoolean("Target Acquired", OnTarget());`
    - After Start-up , SFX will auto-populate panels with new Boolean variables
        - Moved these to GRIP/targets panel as shown above
2. Auto-targeting Behavior in Teleop mode
    - In Teleop mode the operator first drives robot to the vicinity of a target using joystick or gamepad controls
    - A gamepad button is then used to raise or lower the shooter until the target is visible in the camera window
    - Once a target (or targets) are showing the “targets available” indicator turns green (this will also enable the “AutoTargeting” button on the Gamepad)
    - When/if the operator presses the AutoTargeting button, feedback from the position of the target in the images will be used to adjust the horizontal and vertical position of the shooter as described previously
    - When the Auto-Targeting PID loops have finished optimizing the “Target Acquired” indicator in the panel will turn from red to green and the auto-targeting indicator will be reset to “off” (red)

- If the operator then presses the “Shoot” button a ball will be sent towards the target
    - It has been observed that In the simulator a successful shot into the high goal is made almost all the time using auto-targeting



3. Improvements
    - This method still doesn't draw rectangles around the identified targets in the camera window
        - Centered target should be obvious so this is probably not required (but would be a nice feature to have)
    - Since the images in the Camera window are from the input to the GRIP pipeline they don't offer the possibility to show the effect of any GRIP processing
        - On the plus side don't need a “Publish Video” block with this method

Deployment Configurations

Competition

Robot

1. FRC Competition robot or prototype

Processing

1. Image Source
   - Camera: USB, Axis or Pi Camera
   - Connections: Camera to Raspberry Pi via USB slot, Ethernet connector or parallel port
   - Hardware: Raspberry Pi(3)
   - Software: Mjpg-streamer
   - Output: Publishes raw image stream to LAN
     - @ http://raspberrypi.local:1180
2. Image processing
   - Hardware: Raspberry Pi
   - Software: Headless GRIP
   - Connections: 2nd enet port on RoboRio switch connected to raspberry Pi
   - Inputs: image stream from mjpg-streamer
   - Outputs: “NetTables data for target parameters (to local network)
3. Robot Control
   - Hardware: RoboRio
   - Software: FRCUserProgram (Deploy build)
   - Inputs: Reads “NetTables” data for targets from LAN
   - Calculates offsets for Shooter and Robot positioning
     - using target, accelerometer and gyro data
   - Outputs:UI data to LAN (NetTables protocol) for input to Driver Station (SmartDashboard)

User Interface

1. Hardware
   - Widows 10 laptop
2. Software
   - SmartDashboard (original application or JavaFX SFX)
3. Connection: Wireless LAN

- Inputs:
    - Raw Camera images from Raspberry
    - UI data from RoboRio
- Outputs:
    - Image display in Dashboard camera window
    - Targeting Status in Dashboard Widgets (boolean parameters etc)

Simulation

Robot

1. Generated From CAD using Solidworks Exporter
2. Hardware Platform
    - Ubuntu 14 Desktop Laptop
    - NVIDIA Graphics card
    - USB gamepad
3. Software
    - Gazebo 6.5 Simulator
4. Inputs to Simulator
    - gzclient publications from Eclipse robot FRCUserProgram
        - issued by running FRCUserProgram
        - value data for simulated motors etc.
        - routed to Gazebo through plugins
    - Joint information from fields in robot sdf file
        - Fixed data generated by Solidworks SDF exporter
    - Mode control from “sim_ds” Java application
        - Proves interface to switch between Teleop, Autonomous modes etc.
    - Gamepad controls

        - Buttons and joystick knobs
        - Routed to Gazebo from running FRCUserProgram via plugins
5. Outputs
    1. Simulated camera jpg files saved to directory specified in (hand edited) sdf file
    2. gzserver data published to LAN (contains data for simulated encoders etc.)

Processing

1. GRIP running on Ubuntu desktop or Raspberry Pi

User Interface

1. SmartDashboard or SFX

Remote Access (Windows 10)

Setting Up Driver Station to Select SmartDashboard or SFX

SmartDashboard

1. In DriverStation Press Gear Icon
2. Select "Java" as Dashboard Type

SFX

1. Need to edit a startup file
    - Reference: https://wpilib.screenstepslive.com/s/4485/m/26401/l/255410-setting-sfx-to-launch-with-the-ds
    - Change "DashboardCmdLine" in "C:\\Users\Public\Public Documents\FRC\FRC DS data Storage.ini" to point to sfx.jar file (usually in <User-Home>\wpilib\tools directory)
2. Select "Default" dashboard type in driver Station
    - Note: sfx can be really slow to come up

Connecting to the Net Tables Server

1. Whether in Simulation or Deploy Mode the Net-tables Server is hosted on the platform that runs FRCUserProgram (e.g. Ubuntu14 or RoboRio)
2. The Standard Windows Dashboard applications appear to be hard-coded to look for a remote server on the RoboRio with fixed ips (10.xx ..)
3. When either SmartDashboard or SFX is started up from the driver station as described in the

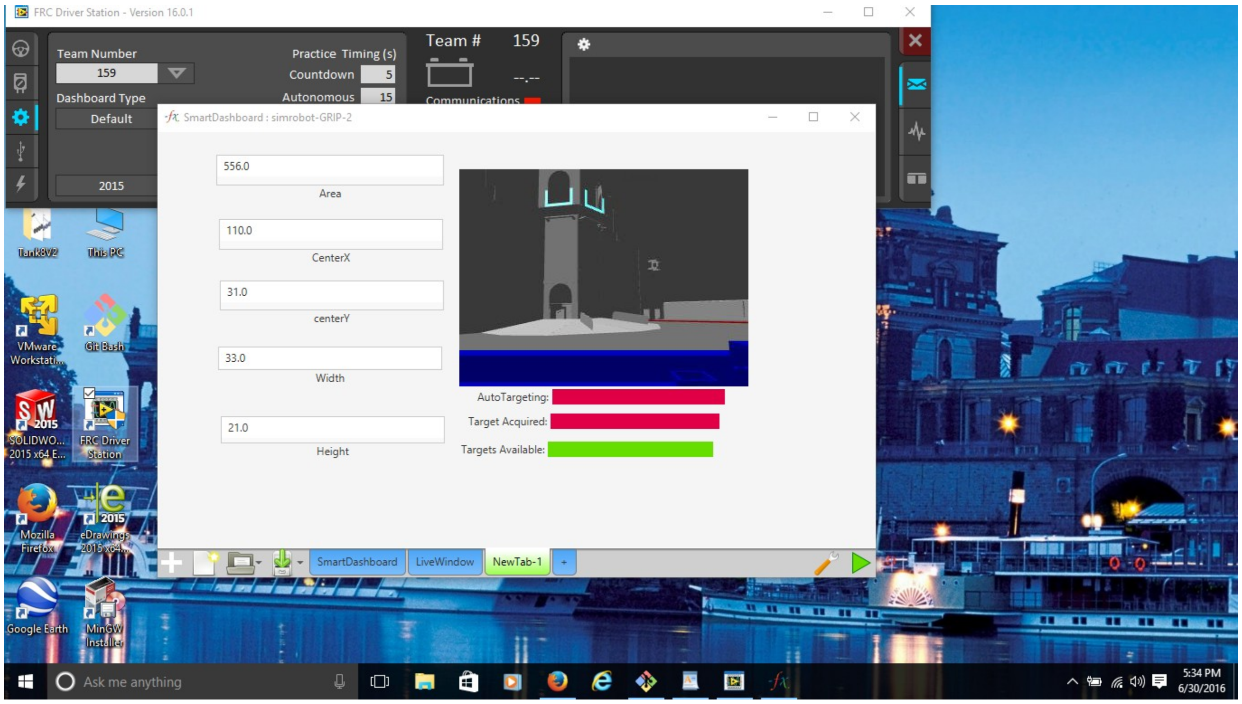
previous section they fail to connect to the Net-tables Server when running in simulation mode because the network address isn't what's expected

Setting Simulation Mode Connections

1. Connecting to SmartDashboard

   SmartDashboard does provide a command line option that can be used to specify a remote net-tables server

   - The syntax is: java -jar <path to wpilib tools>/smartdashboard -ip <ip of remote server>
     - e.g. java -jar C:\Users\<user>\wpilib\tools\smartdashboard.jar -ip 192.168.1.101
       - Regrettably, the ip argument seems to be limited to a numeric string and DHCP names like Ubuntu14.local aren't recognized
     - This method could be used to start SmartDashboard from a DOS command script but haven't determined if that could be configured to run when the user selects the "Java" Dashboard type from the driver station
2. Connecting to SFX
   1. Start sfx.jar with a remote Net Tables server using a command line string
      - Syntax: java -jar <path to wpilib tools>/sfx.jar -nwt://<ip of remote server>
      - e.g. java -jar ~/wpilib/tools/sfx.jar -nwt://192.168.1.101
      - As in SmartDashboard, the "ip" needs to be a network number
        - DHCP names like Ubuntu14.local don't seem to work
   2. Set a new connection Source in the sfx interface
      - Open sfx interface (e.g. java -jar sfx.jar)
      - Press the "+" button
      - Press the "Connections" icon on lower left (looks like a group of arrows)
      - In the "Data Source Selector" panel that comes up press the "Add Data Source" button
      - Set "type" to "NetworkTables"
      - Set "Host" to ip of remote server (e.g. 192.168.1.101)
        - Again, ip must be numeric
      - Press "Save"



556.0
Area
110.0
CenterX
31.0
centerY
33.0
Width
21.0
Height
AutoTargeting:
Target Acquired:
Targets Available:

Interacting with Gazebo simulation from Windows

Remote Gamepad or Joystick control

Control Device connected to USB port on Windows PC

1. Using FRC driver station
   - Would need to fool DS into thinking FRCUserProgram running on remote Ubuntu was actually a Roborio
     - Not sure about how the connection is supposed to work but it probably needs some RoboRio specific service that's not supported in simulation
2. Using sim_ds
   - Would need to run this Java application on Windows and attach it to a remote gzserver
     - Don't know if sim_ds runs on Windows or if it can be attached to a remote gzserver

Through SFX or SmartDashboard Controls

Send messages using Net Tables protocol to change Mode etc. using panel controls instead of a Joystick and sim_ds buttons

1. Create a control to invoke a Command when pressed
   - In c++ code add a command to a Constructor (or RobotInit)
   - e.g. in OI::OI() add: SmartDashboard::PutData("ToggleGate",new ToggleGate());

- When Smart dashboard starts a new Button called “ToggleGate” will appear in the panel
- Disable “edit” mode to use the button
    - In SmartDashbord change the “view” status to “editable”
    - In SFX press the “Play” button (green arrow) in lower right of main window
- Pressing the button caused the command to be executed in the simulation

2. Proposal: Create a Widget to switch between Control modes (Teleop, Autonomous & Disabled)
    - `Write C++ Commands to Set the Operation Mode the state of a variable as described above`
    - `In Robot Constructor add SmartDashboard::PutData commands to attach the commands to buttons`
    - In C++ code create Robot class overrides for `IsAutonomous() & IsDisabled()`
        - `could also include IsTest() override`
        - `note: teleop is the default (there is no IsTeleop function)`
    - `In IsAutonomous() & IsDisabled() functions merge conditions from SFX Commands (set via buttons) with state commands issued from sim_ds (using network protocol)`
        - `e.g. psuedocode for IsAutonomous()`
            - `If SFX Autonomous button is pressed return true`
            - `else return RobotBase::IsAutonomous()`

Advanced Topics

“Deep Learning” For Game Object Recognition

For a much more in depth discussion of these topics refer to the document “AdvancedAITools.odt” in this git-hub directory

Motivation

Train a simple classifier to recognize objects in a Gazebo simulation

This test will attempt to train a neural network to recognize ball and tote objects randomly placed in the 2015 FRC “recycle rush” field. The camera can be mounted on any drivable simulated robot (for convenience the 2016 bot will be used with the camera position raised slightly)

1. Generate a vision test Gazebo “world” file
   - Set GAZEBO_MODEL_PATH to point to the directories that contain the models that will be used
     - $ export SWMODEL=$SWEXPORTS/2016-Robot_Exported
     - $ export GAZEBO_MODEL_PATH=$SWMODEL:$GAZEBO_MODEL_PATH
     - note: ~/.gazebo is included automatically
   - Start up gazebo
     - $ gazebo
   - Insert frc_field_2015
   - Insert 2016-robot
   - Insert and randomly place:
     - 2 gray totes (from 2015 game)
     - 2 balls (from 2016 game)
   - save world as (e.g. vision-test.world)
2. World file tweaks
   - Open “vision-test.world” in a text editor
   - Modify sensor block to set image capture rate
     - find: <sensor name='ShooterCamera' type='camera'>
     - add: <update_rate>2</update_rate>
       - e.g. capture 2 frames a second
   - Modify camera position in sensor block (increase height from ~0.1 to 0.5)
     - <pose frame=''>-0.124207 0.5 -0.122065 1.5708 -0 3.14159</pose>
   - Modify camera block to save images into a directory (e.g. /tmp/shooter-camera)
     - find: <camera name='Shootercamera'>
     - add: <save enabled='1'> <path>/tmp/shooter-camera</path> </save>
3. Run a gazebo simulation and capture a set of images while driving around the field

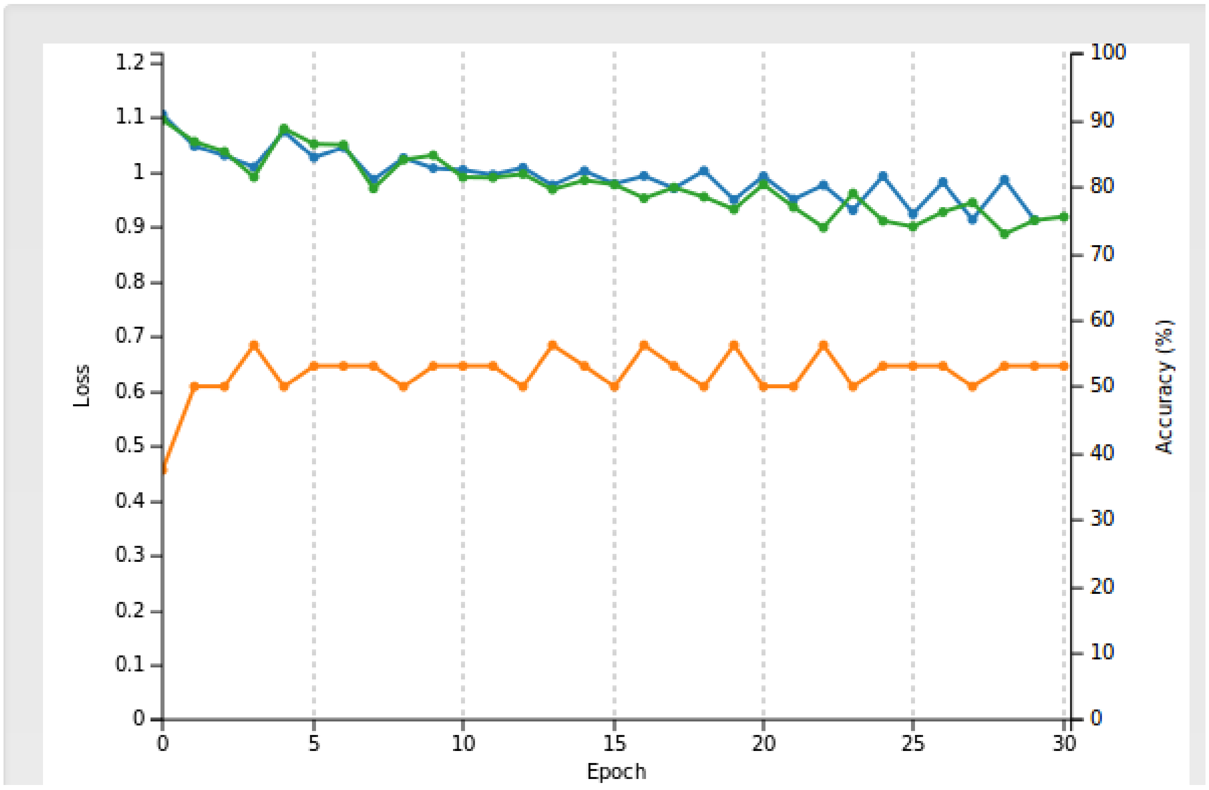
- Start up gazebo with the “ vision-test.world” file
  - export GAZEBO_MODEL_PATH as shown previously
  - $ gazebo vision-test.world
- Start up sim_ds
  - open a new terminal or tab
  - make sure gamepad or joystick is connected to a USB port
  - $sim_ds
- Start up FRCUserProgram
  - open a new tab or terminal
  - cd ../MentorRepository/Software/workspace/SimVisionTest
  - ./FRCUserProgram
- Enable “teleop” mode in sim_ds
- “visualize” the gazebo shooter-camera topic
- Using the gamepad, drive the robot around the field
  - try to capture images that show totes, balls or none of the above
  - a new image will be added to /tmp/shooter-camera at the update_rate specified in the world file
- Exit gazebo,sim_ds and FRCUserProgram

4. Create a set of labeled directories that will be used to generate a DIGITS data set
   - Create a parent directory
     - mkdir -p ~/data/vision-test && cd ~/data/vision-test
   - Create a sub-directory for each object type
     - mkdir ball tote none
   - Populate the 3 sub-directories
     - Open a “Places” browser and browse to /tmp/shooter-camera
     - Select “View items as a grid of icons”

        - After a short simulation run at 2 frames/s there were ~80 images collected
    - Open a second “Places” browser and browse to ~/data/vision-test
    - Hand select and move images from /tmp/shooter-camera to ~/data/vision-test/ball that show only a ball in the field (no tote)
    - Do the same (to ~/data/vision-test/tote) for images that show only a tote
    - Move to ~/data/vision-test/none images that show neither

5. Create a DIGITS data set
    - Open DIGITS in a web browser (http://localhost)
        - If installed correctly the DIGITS web-server should be running after bootup
    - Select DIGITS/Datasets
    - Select new dataset->classification
    - Set image size = 320 x 240
    - Set resize transformation = squash
    - In “Training Images” field browse to ~/data/vision-test
    - Select 25 % for validation and 10 % for testing
    - Uncheck “Separate ..” checkboxes
    - Keep other option defaults
    - Set “Dataset Name field” to something (e.g. “ball_tote”)
    - Press “Create”
        - After a short delay a new DIGITS dataset should be created
6. Attempt to train a neural network from scratch on this dataset using “Alexnet”
    - In the DIGITS browser window select DIGITS->new Model->classification
    - In the “Select Dataset” list choose the dataset just created (e.g. “ball_tote”)
    - In the “Standard networks”/”Caffe” list choose “Alexnet”
    - Enter a name for the model (e.g. AN on ball_tote)
    - Press “Create”

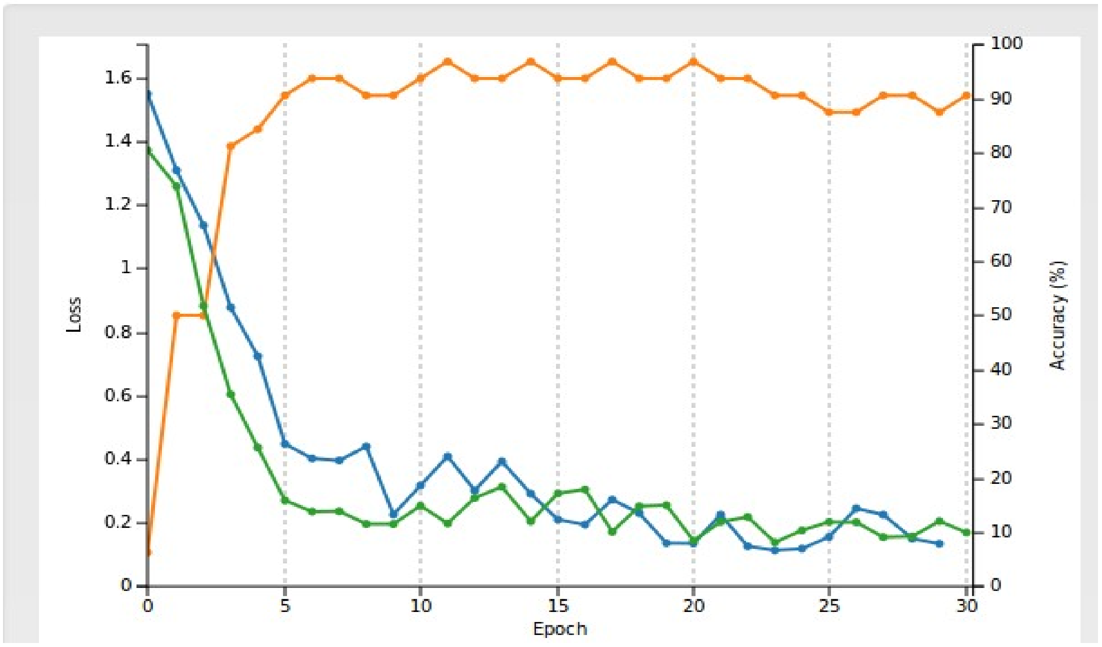
- After a short while (2-3 minutes) the training will complete
- Results:



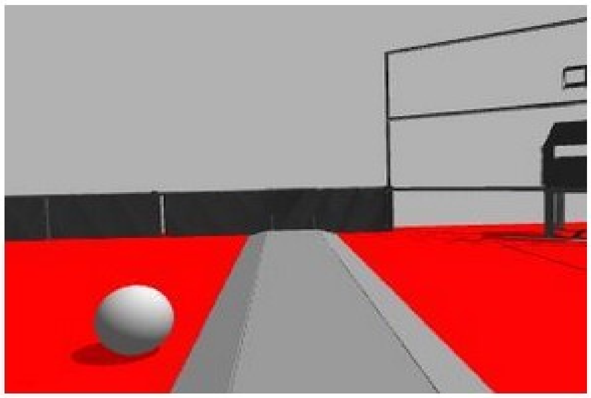
- In this attempt the accuracy is fairly poor (55%) in identifying the 3 categories (random success would be 33%)

7. Use a pre-trained network to improve results
    - In DIGITS Select Models → Images → Classification
    - Again select "ball_tote" as the dataset
    - Keep solver options the same as before except reduce the learning rate from 0.01 to 0.002
    - In the "standard networks" list, again select "Alexnet"
    - Press "customize" to the right of the radio-button (this will show the Caffe Alexnet network in text format)
    - In the network text window change all instances if "fc8" to "fc9" (should be 5 of then at the bottom)
    - In the "pre-trained model" entry field browse to the location of a previously downloaded Alexnet ".caffenet" file (e.g. ~/caffe/models/bvlc_alexnet/bvlc_alexnet.caffemodel

    - see AdvancedAITools.odt for installation instructions
- Give the new model a name (e.g. “pre-trained AN on ball_tote”)
- Press “Create”
- Results

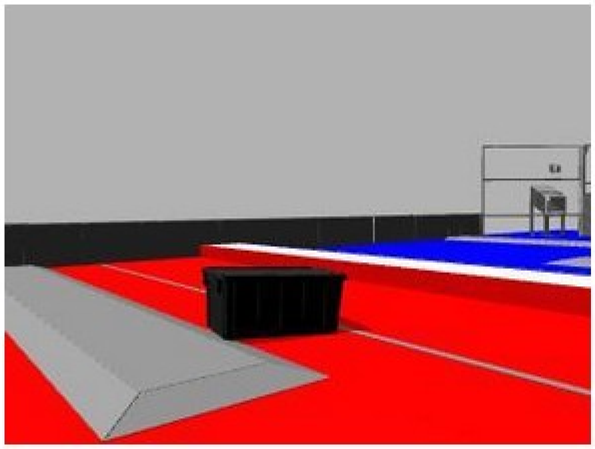


- Note: accuracy is now > 90 %
- Test the classifier on a sample image
    - In the model “Test a single image” field browse to one of the images in the 3 sub-directories
    - Press the “Classify One” button
    - Results:



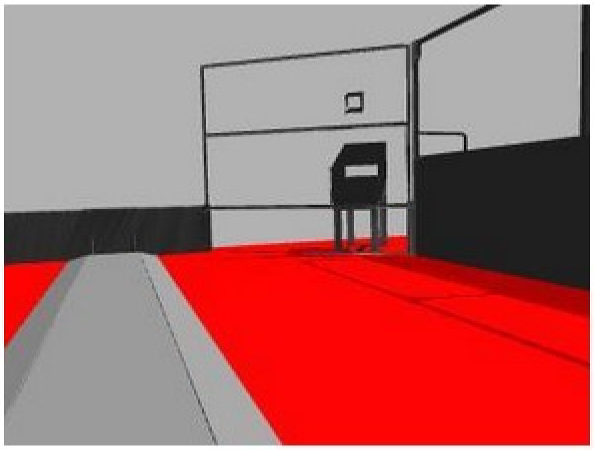
Predictions

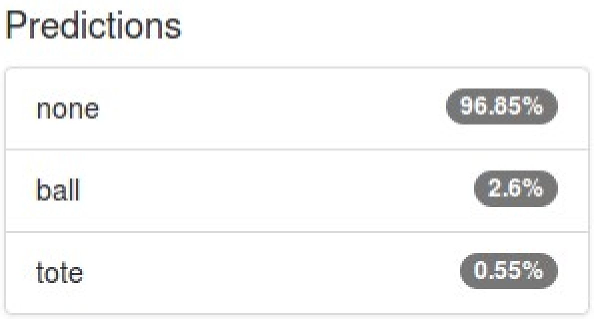
ball	99.77%
none	0.16%
tote	0.07%



Predictions

tote	99.21%
none	0.79%
ball	0.0%





Predictions

none	96.85%
ball	2.6%
tote	0.55%

8. Comments
   - While sufficiently accurate in labeling full size images that contain one of a select group of objects the method as it stands would not be suitable as a means for determining target properties (such as distance and offset angle) in real time since no information on where the classified object is in the image is given
     - In AdvancedAITools.odt methods that generates bounding boxes around target objects found in larger images are described
   - Identification speed will probably be an issue when running on less powerful hardware
     - Using command line arguments to classify an image trained with this network (see AdvancedAITools.odt) reported an identification time of ~50 ms on a high end graphics card (NVIDIA GTX 980)
       - Based of previous benchmark tests the same classifier running on a Jetson TK1 would probably be ~20x slower (e.g. 1 Hz) which would be inadequate for real time analysis (even before bounding box generation is attempted)
     - Using the fast-rcnn network (see AdvancedTools) has been shown to improve speed and accuracy performance significantly over the standard networks provided in DIGITS. It is also designed to generate bounding box proposals around detected objects
   - Some evidence suggests that identification time may be proportional to image size so it may be possible to get better performance by reducing the size of the images used to train the network (see next sections)
9. Optimization Modifications
   - Classify only one object type

    - ball only, field only

- Reduce the dimensions of the images created
    - 320x240 - > 32x32
        - Modify camera-sensor block in sdf file
- Reduce the horizontal FOV
    - 1.0->0.5
        - Modify camera-sensor block in sdf file
    - note: objects may only be detected when directly in front of the camera
- Train with LE net (vs. Alexnet)
    - LENet trains on 28x28 grayscale images
- collected images
    - FPS: 5
        - Modify camera-sensor block in sdf file
    - Number of ball images : 85
    - Number of field images: 100
- Results
    - Accuracy (test): 85%
    - processing time (multiple images) 3-4ms/image

Train a Neural Network to find bounding boxes for objects in a Simulated FRC field

The general class of methods used to detect “boxes” around objects in images is called “Object Detection”. Some good high performance technique in this area are:

1. FASTER R-CNN (”Regional Convolutional Neural Networks”)
2. YOLO (“You Only Look Once”)
3. SSD (“Single Shot Multi-box Detector”)

References

FASTER-RCNN

1. Additional details for the setup of a python based faster r-cnn development are given in a companion document: “AdvancedAITooools” in the MentorRepository Softeare/Docs directory

2. Main source code repository: https://github.com/rbgirshick/py-faster-rcnn
3. Modifications for use on a custom dataset
   - https://github.com/deboc/py-faster-rcnn/blob/master/help/Readme.md
   - https://huangying-zhan.github.io/2016/09/22/detection-faster-rcnn.html
   - https://github.com/andrewliao11/py-faster-rcnn-imagenet/blob/master/README.md

YOLO (You only Look Once)

1. https://pjreddie.com/darknet/yolo/
2. https://arxiv.org/pdf/1612.08242.pdf

SSD (Single-Shot multi-box Detector)

1. https://github.com/weiliu89/caffe/tree/ssd

Dataset creation (General procedure)

Create a dataset that contains only a small class of objects (e.g. totes,balls)

1. Generate a set of annotated images
   - Use images obtained from a Gazebo simulation (e.g. 2015 FRC field)
   - create a Gazebo world file populated with target objects
   - Insert a simple robot model with a simulated camera
   - use an Eclipse tank drive project to control the robot model in teleop mode
   - set the camera capture rate to a low value (0.5 FPS ?) and enable image save
     - add <update_rate>0.5</update_rate> to camera sensor section in world file
   - drive around the scene and collect a set of images containing balls and totes (or none) in the gazebo field
2. Rename image files in directories (optional)
   - The Gazebo camera sensor names files in it's own way that produces some rather long file names like: “default_SimBot_Chassis_ChassisCamera(1)-0214.jpg”
   - The following Unix command line can be used to shorten the file names to just the part containing the number :

     ```
     $ for file in *.jpg; do mv "$file" "${file/default_SimBot_Chassis_ChassisCamera(1)-/}"; done
     ```

    - part to replace is after first “/” and the replacement text is after the second “/” and before the “}” (in this case none)
    - e.g. default_SimBot_Chassis_ChassisCamera(1)-0214.jpg -> 0214.jpg

3. Create bounding-box “ground truth” proposals for the set of images (imagnet xml format)
   - “labelImg” - utility for generating bounding box annotations by hand
     - Get source code and build tool

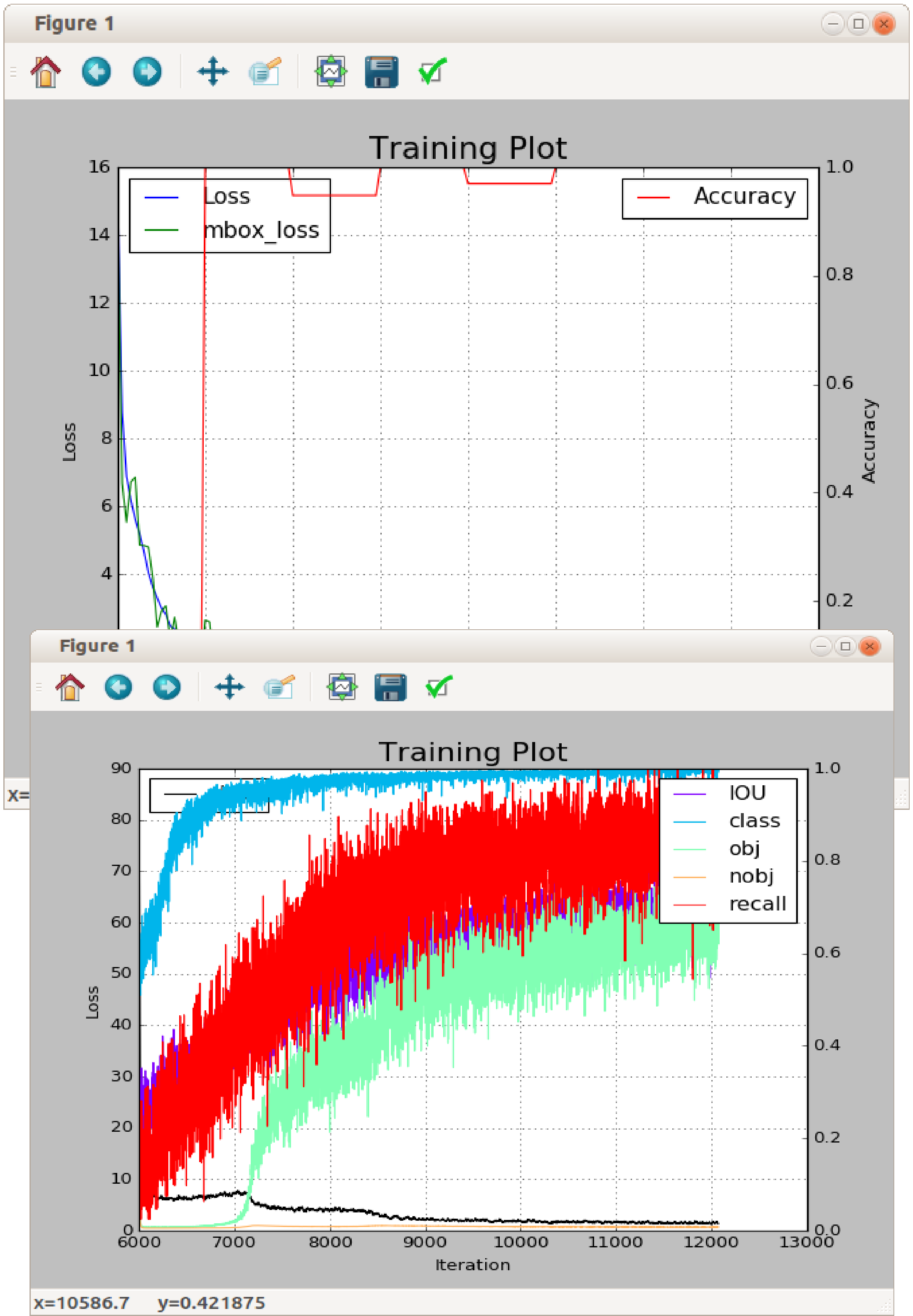
       ```
       git clone https://github.com/tzutalin/labelImg
       cd labelImg
       sudo apt-get install pyqt4-dev-tools
       make all
       ```
     - usage:
       - start up python app
         - `python labelImg.py`
       - `In app Open directory of saved images`
       - `In app open each image in directory and draw bounding boxes around totes and balls`
       - `save annotations`
       - `Use “next” to load next image and repeat above steps`
4. Set up data directories and files
   - ImageSets
     - a list of filenames (paths) for train and test images
       - possible text files: test.txt train.txt
   - data path structure (from data root directory)
     - e.g. Images
       - <unique_name>.jpg
       - e.g. 001330.jpg
     - Annotations
       - <unique_name>.xml

Train the network

1. Training is best carried out on a high end Linux based computer with a good graphics card. For the tests described below a 6-core AMD system with an NVIDIA GTX-980 was used. The OS was Ubuntu 14.04 (testing was also done using a Ubuntu16.04 laptop with an NVIDIA GTX 640m gpu)

2. Sample training plots

   - ssd-caffe 300x300 BallTote dataset

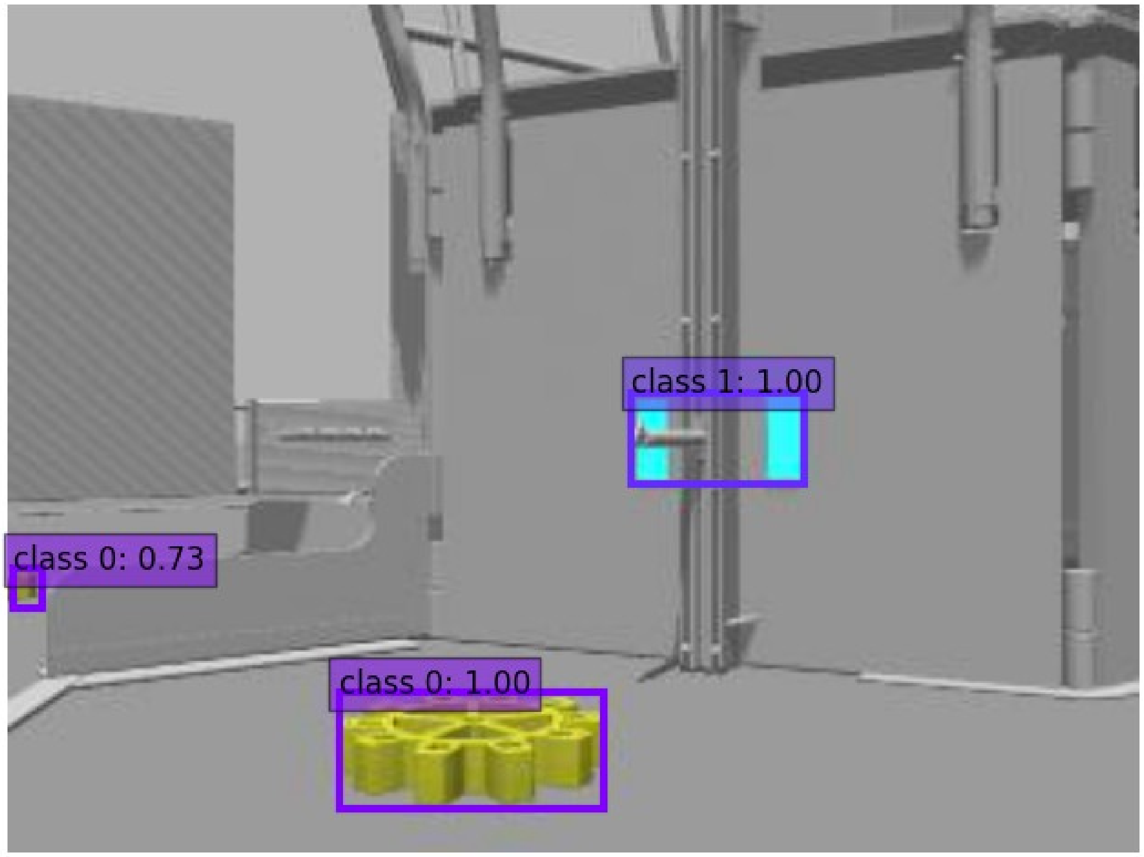


- yolo 2.0 300x300 TapeGear data set

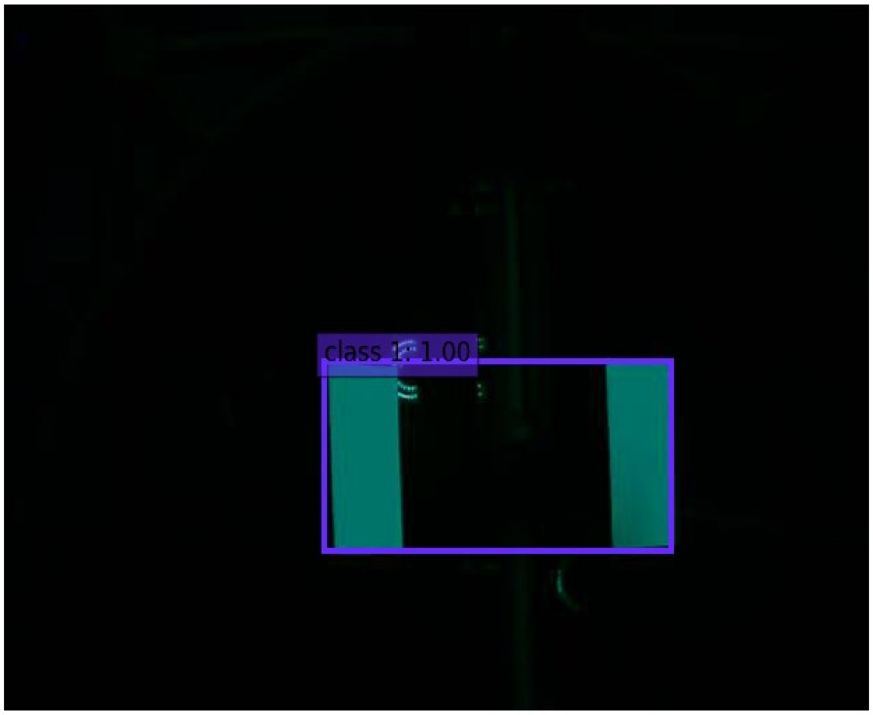
Test Results

1. ssd-caffe (300x300) TapeGear data

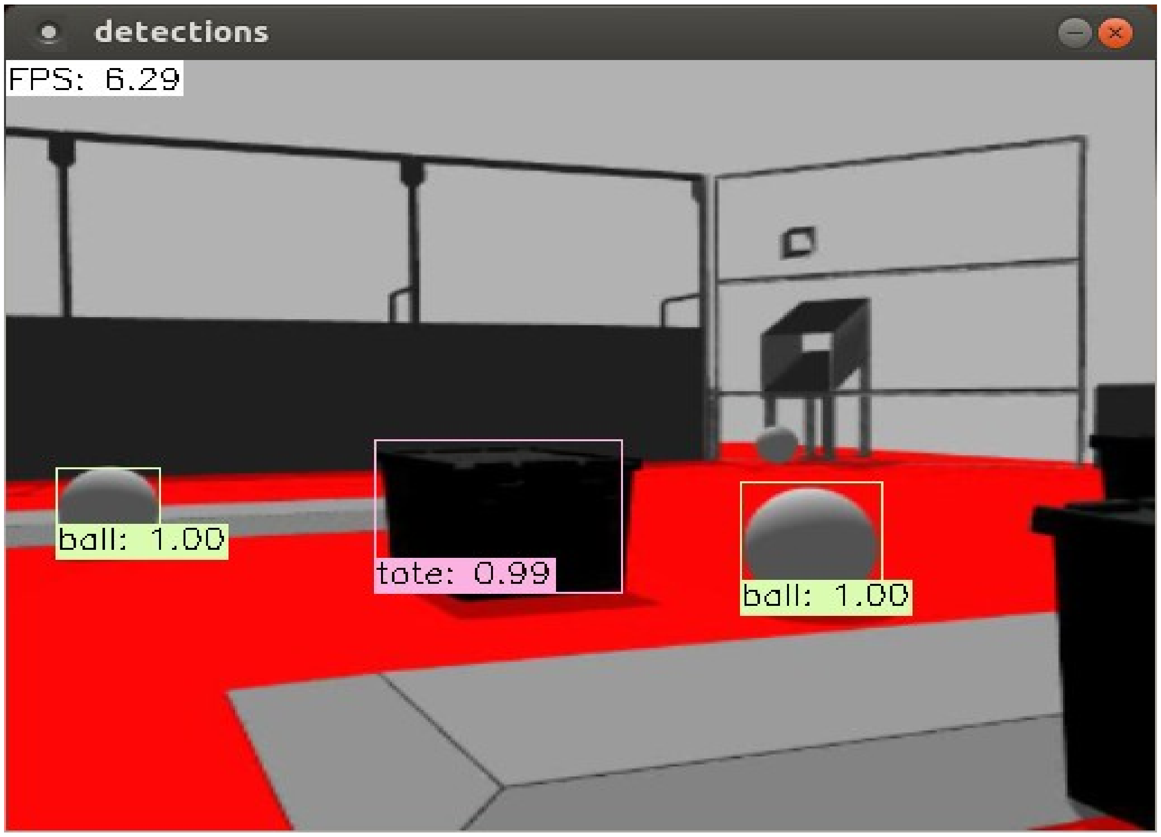
- Sample images from Gazebo simulation



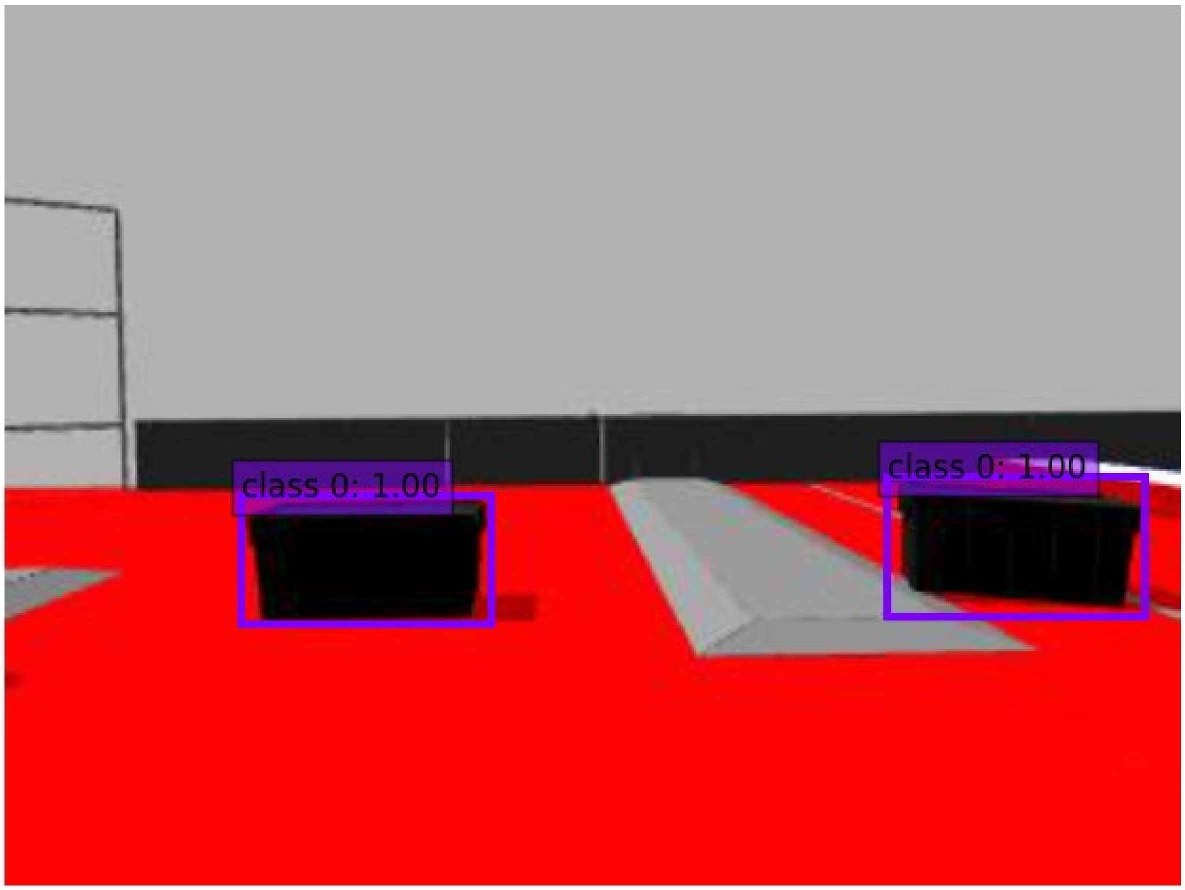
- Sample downloaded (real) FRC Field images



2. ssd-caffe 300x300 BallTote data



3. yolo 300x300 BallTote Data

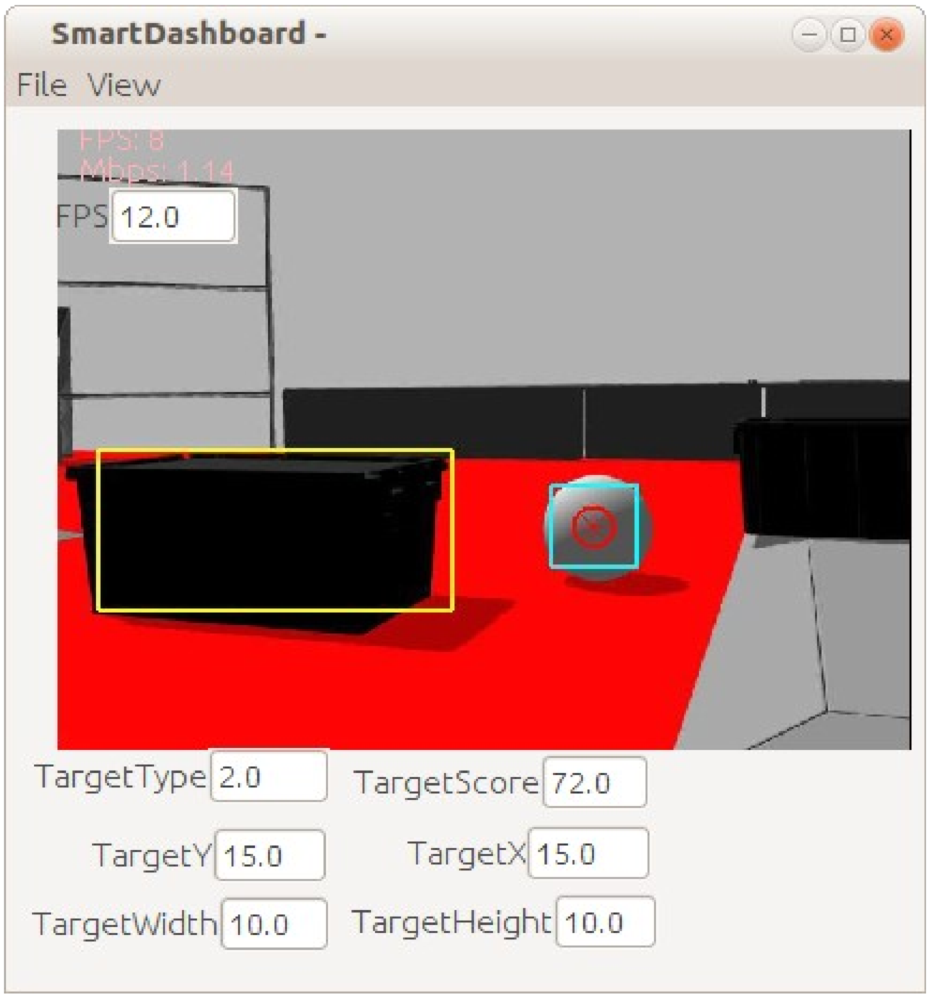


Port to RT hardware

1. Jetson TK1 ($192 from NVIDIA)
   - Was able to successfully port ssd-caffe (but not yolo)
   - ssd-caffe
     - could not build with CUDNN enabled (requires later versions of cuda libs than are supported on the TK1)
     - framerate for ssd-caffe was only 1.3 FPS
   - yolo
     - Had problems building darknet natively, primarily because the TK1 arm is a 32 bit CPU

and the build scripts assume 64 bit support

2. Jetson TX2 $300 from NVIDIA – with educational discount (normally $600)
   - 64 bit ARM architecture running a RT version of Ubuntu 16.04
   - was able to build both ssd-caffe and yolo natively
   - RT performance (processing, cycle update rate)
     - ssd-caffe 300x300: 7 FPS (6)
     - yolo 300x300: 12 FPS (8)
   - Sample SmartDashboard screenshots
     - yolo streaming video from gazebo simulation



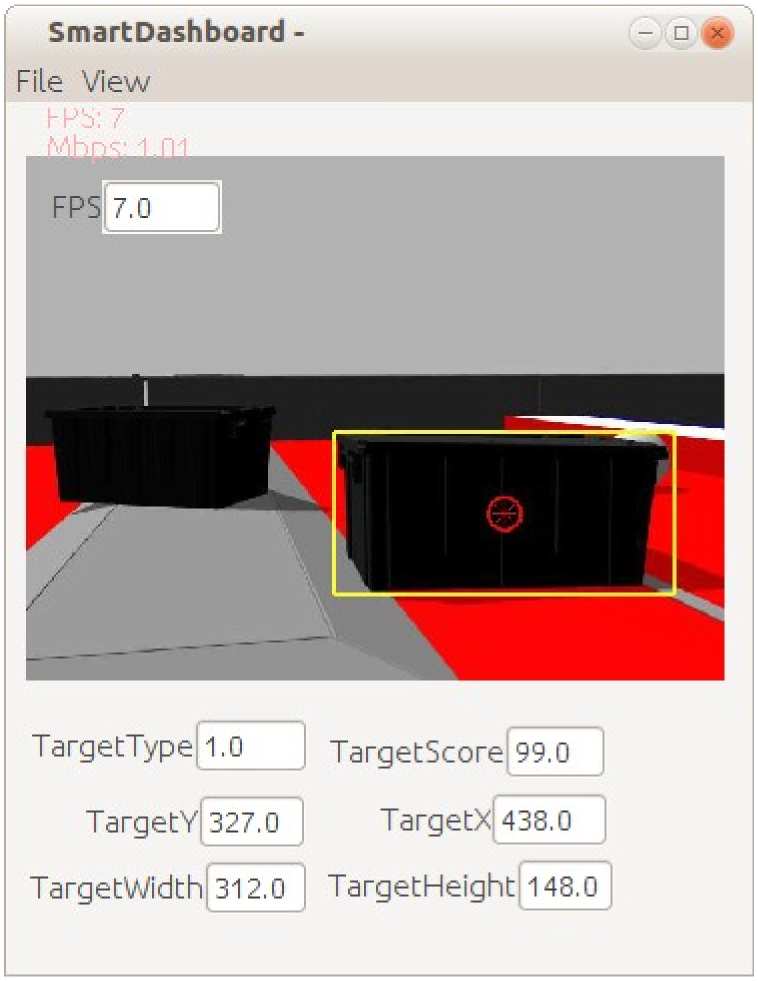
FPS 12.0

TargetType 2.0 TargetScore 72.0

TargetY 15.0 TargetX 15.0

TargetWidth 10.0 TargetHeight 10.0

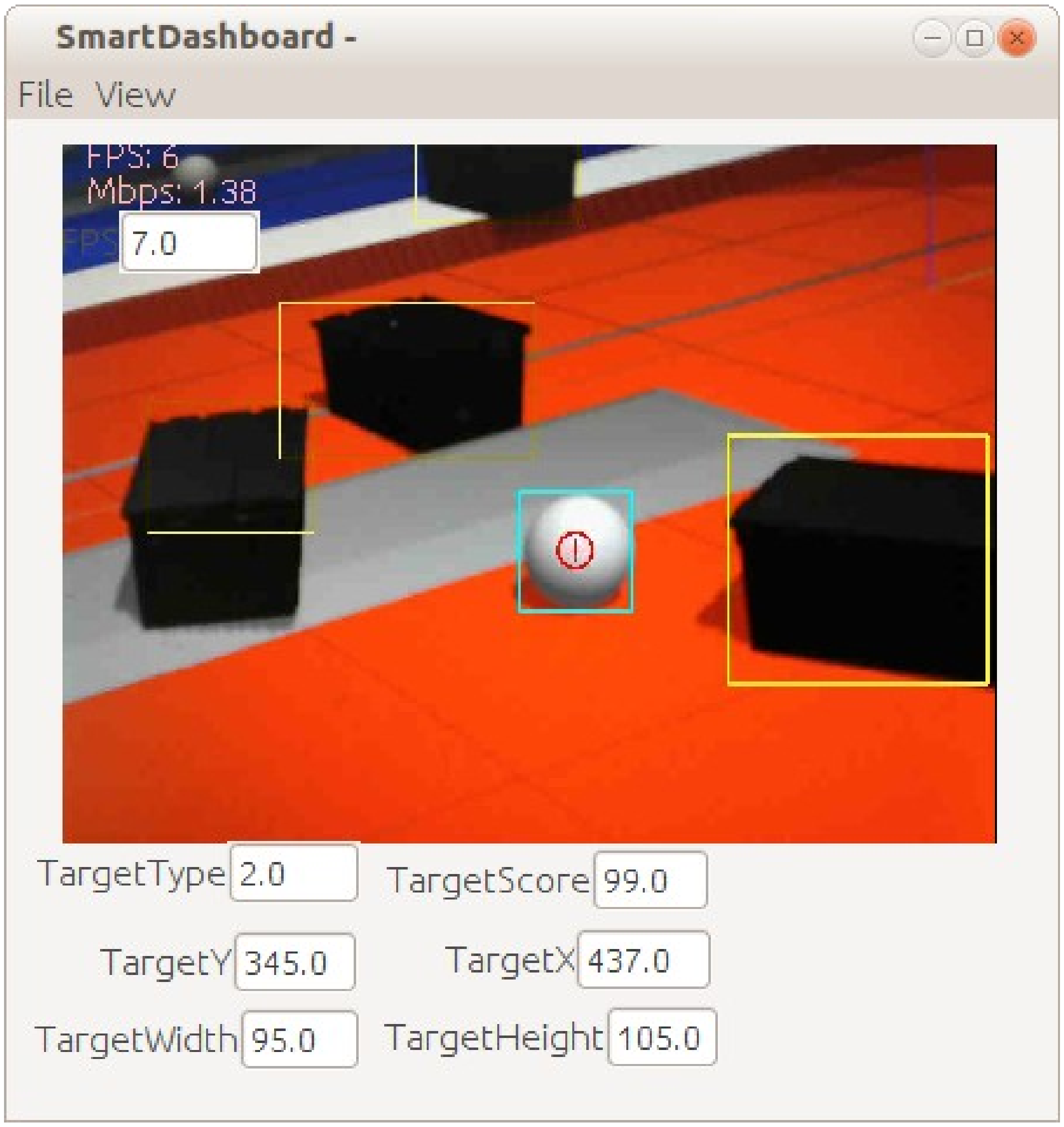
     - ssd-caffe streaming video from gazebo simulation



FPS 7.0

TargetType 1.0
TargetScore 99.0
TargetY 327.0
TargetX 438.0
TargetWidth 312.0
TargetHeight 148.0

- streaming video from camera (Logitech c270) pointed at monitor where a gazebo simulation was running



FPS 7.0

TargetType 2.0
TargetScore 99.0
TargetY 345.0
TargetX 437.0
TargetWidth 95.0
TargetHeight 105.0

- Other results
  - Replaced “GRIP” targeting code used in 2017 game with ssd-caffe code running on the TX2
    - able to place gear in autonomous mode from center position
    - vision assist in teleo mode also worked as well or better than when using the GRIP vision code

3. Comments and observations

- Overall the Jetson TX2 appears to have enough processing power to serve as a viable “deep learning” alternative to color-only based image processing methods (e.g. GRIP, NIvision)

- The TK1 probably would be too slow to provide sufficient RT performance

Appendix 1: Summary of Build Targets

Mjpg-streamer

Supported Software Platforms: All Linux

Supported Hardware Platforms: x86_64 mainframe, Raspberry Pi

GRIP

Supported Software Platforms: Ubuntu 14.04, Windows (untested)

Supported Hardware Platforms: x86_64 mainframe, Raspberry Pi (headless)

FRCUserProgram

Supported Software Platforms: Ubuntu 14.04, RoboRio (Linux OS)

Supported Hardware Platforms: x86_64 mainframe, RoboRio

SmartDashboard (Java based)

Supported Software Platforms: Ubuntu 14.04 , Windows

Supported Hardware Platforms: x86_64 mainframe

SFX (JavaFX based)

Supported Software Platforms: Ubuntu 14.04 , Windows

Supported Hardware Platforms: x86_64 mainframe

Solidworks SDF Exporter

Supported Software Platforms: Windows 10

Supported Hardware Platforms: x86_64 mainframe

sim_ds

Supported Software Platforms: Ubuntu 14.04

Supported Hardware Platforms: x86_64 mainframe

DIGITS

Supported Software Platforms: Ubuntu 14.04

Supported Hardware Platforms: x86_64 mainframe