Autonomous Ground Support Equipment Design, Construction & Implementation

NASA Student Launch Initiative

2014-2015

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Vanderbilt Aerospace Club

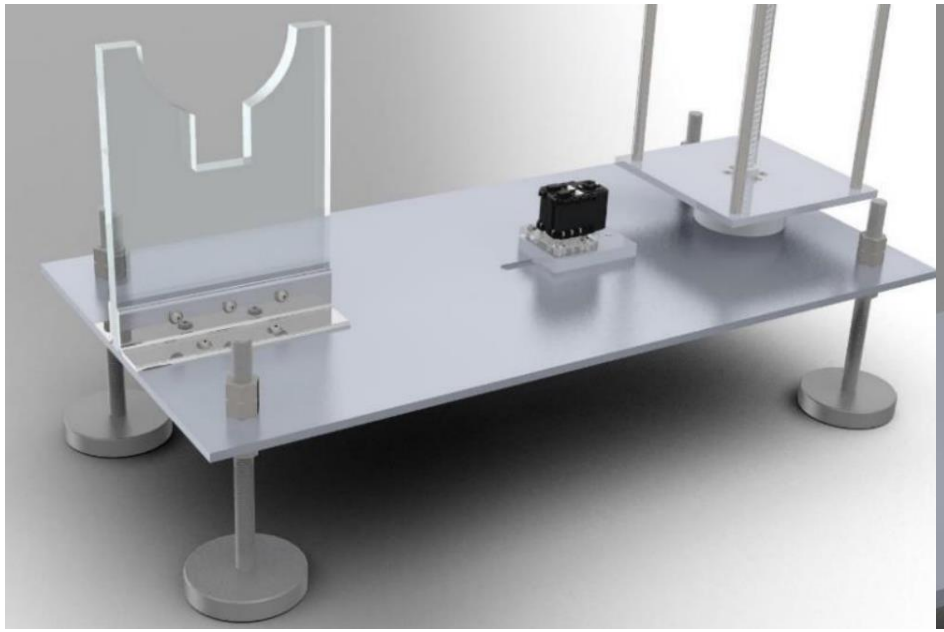
The 2014-15 Aerospace Club was sponsored by the Department of Mechanical Engineering and the Boeing Corporation.

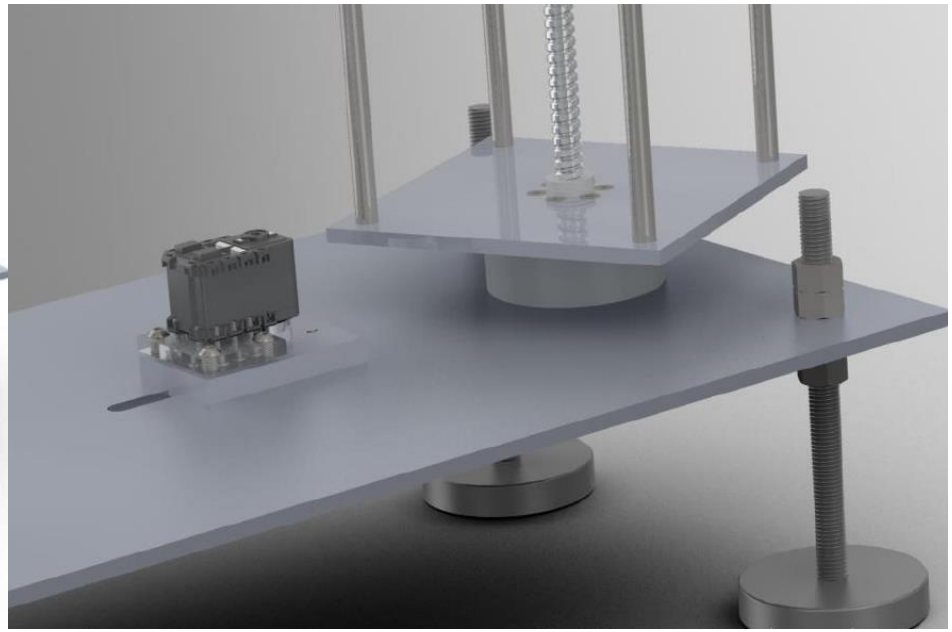
Overview

- Autonomous Ground Support
  - Sample Retrieval
- Design Goals
  - Reliability
  - Simplicity
  - Robustness
- Design Considerations
  - Minimum degrees of freedom
  - Image Processing
  - Distributed Embedded System
  - User Input Panel
  - Model-driven software development

Mechanical Construction (1/3)

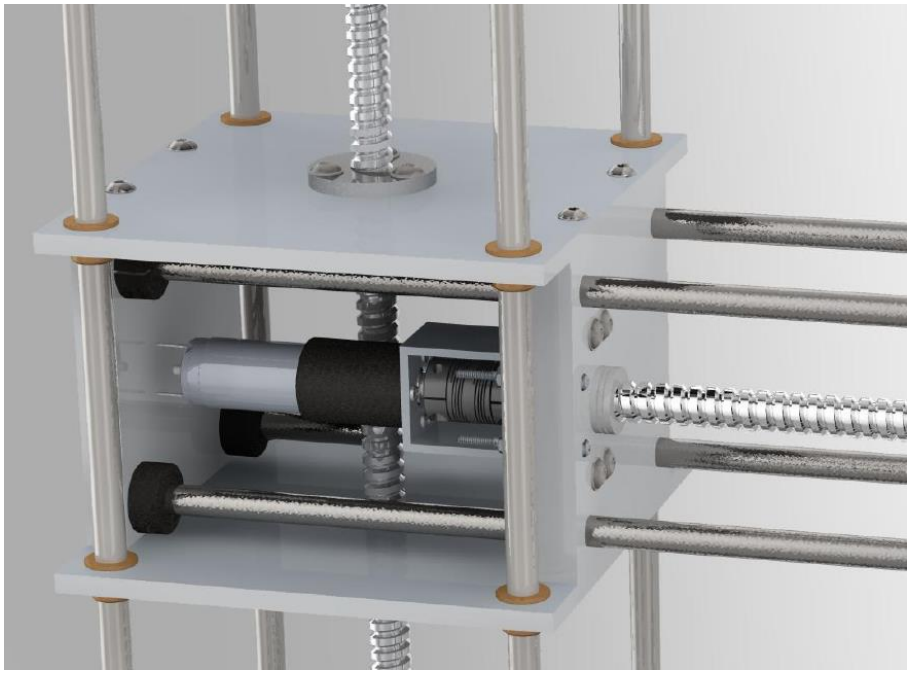
- AGSE Base Table
  - 25.5” tall and up to 19.5” radial reach
  - Adjustable leveling feet
  - Rocket stand and Base rotation system

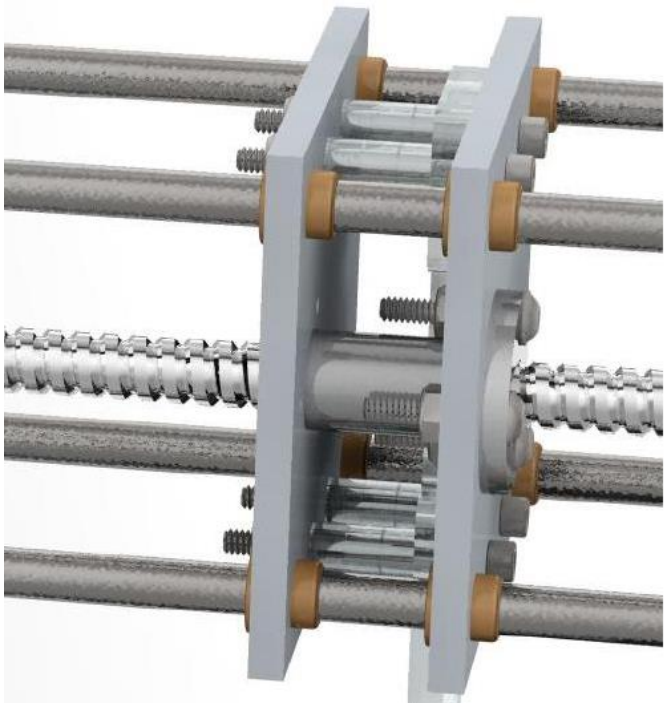




Mechanical Construction (2/3)

- Lead Screw Linear Actuation
  - Faulhaber 12V, 8.1W motors
  - Vertical carriage supports a horizontal powertrain

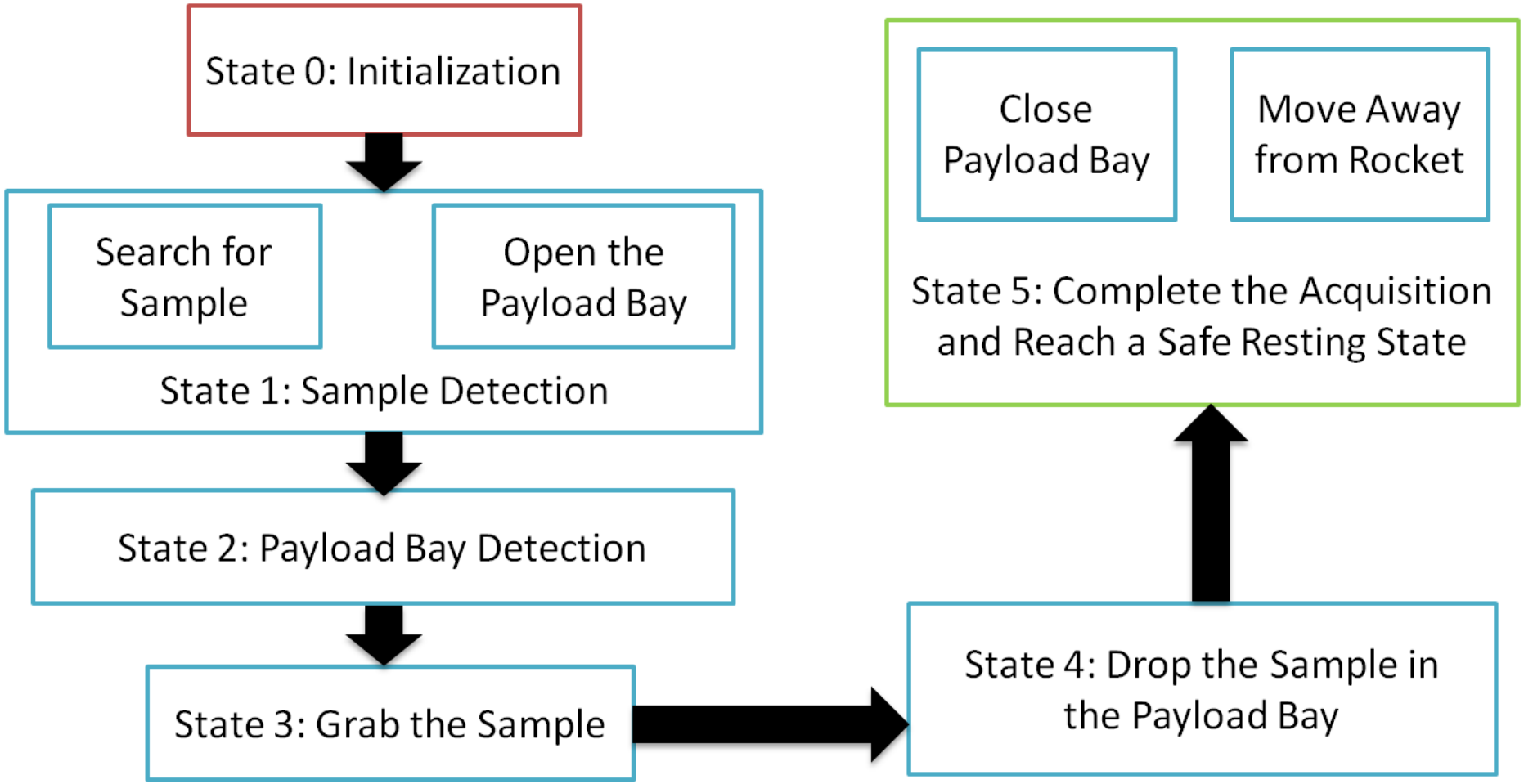




Mechanical Construction (3/3)

- AGSE Gripper
  - Optimized phalange curvature
  - Acrylic “gear box”

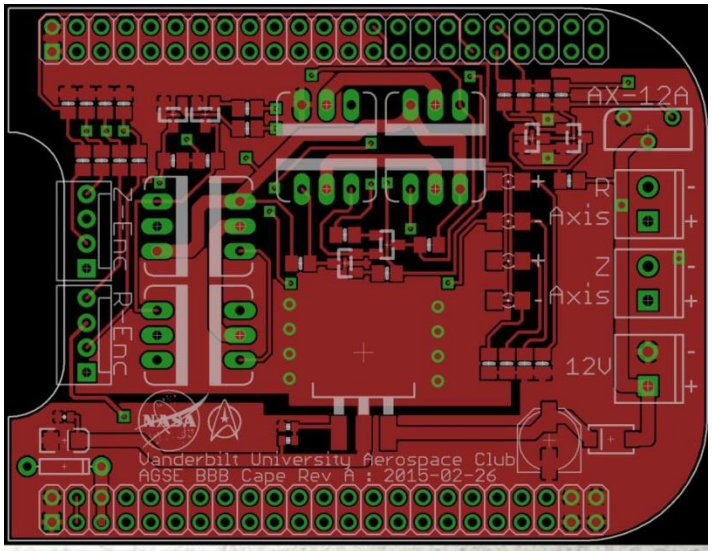
AGSE Overview

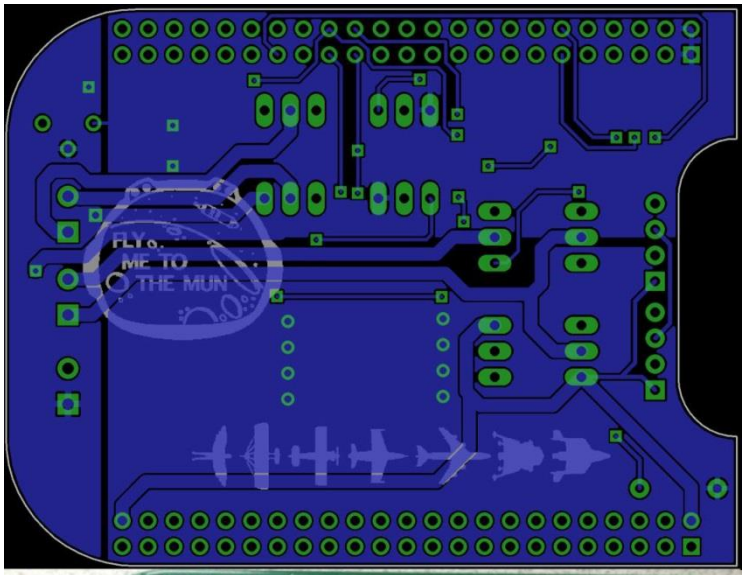


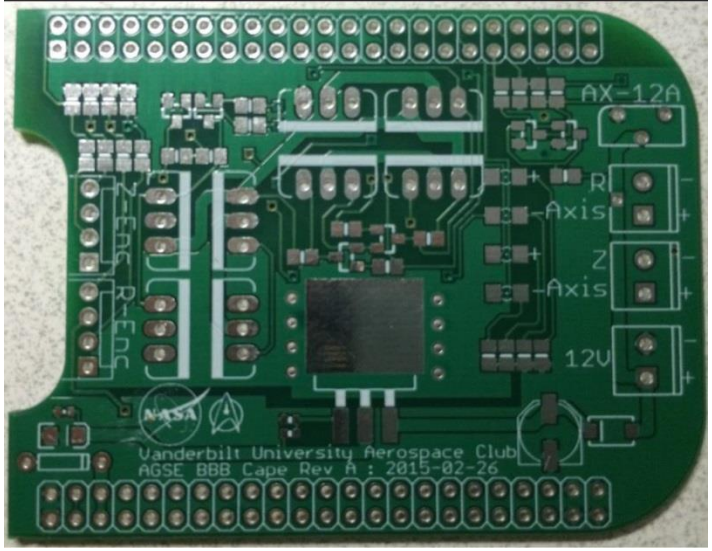
AGSE Electronics (1/3)

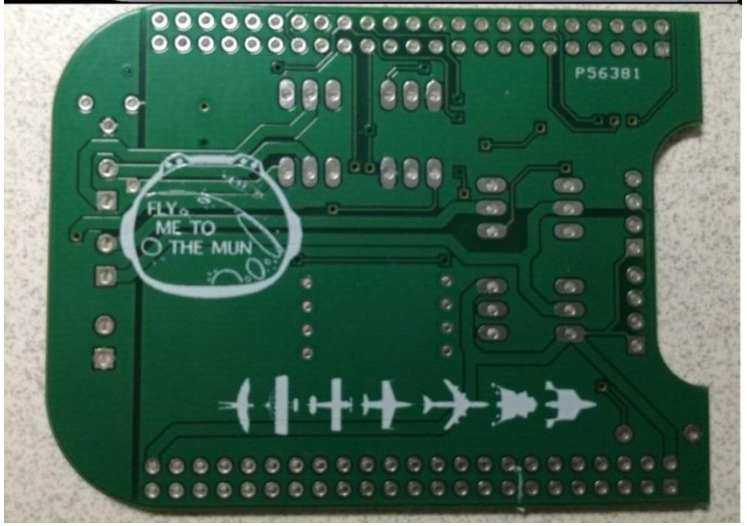
- Custom PCB
  - Attaches to the BeagleBone Black as a cape
- Provides power & functionality for
  - Serial buffer for UART
    - 3.3V to 5V for servo control
  - H-Bridge for Vertical Actuation Motor
  - H-Bridge for Radial Actuation Motor
  - Radial axis quadrature encoder
  - Vertical axis quadrature encoder

AGSE Electronics (2/3)

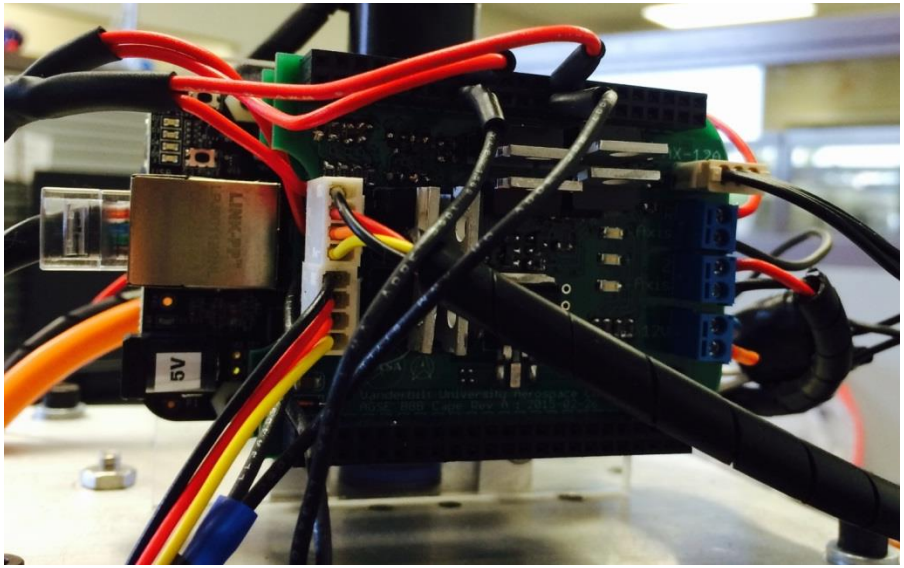








AGSE Electronics (3/3)



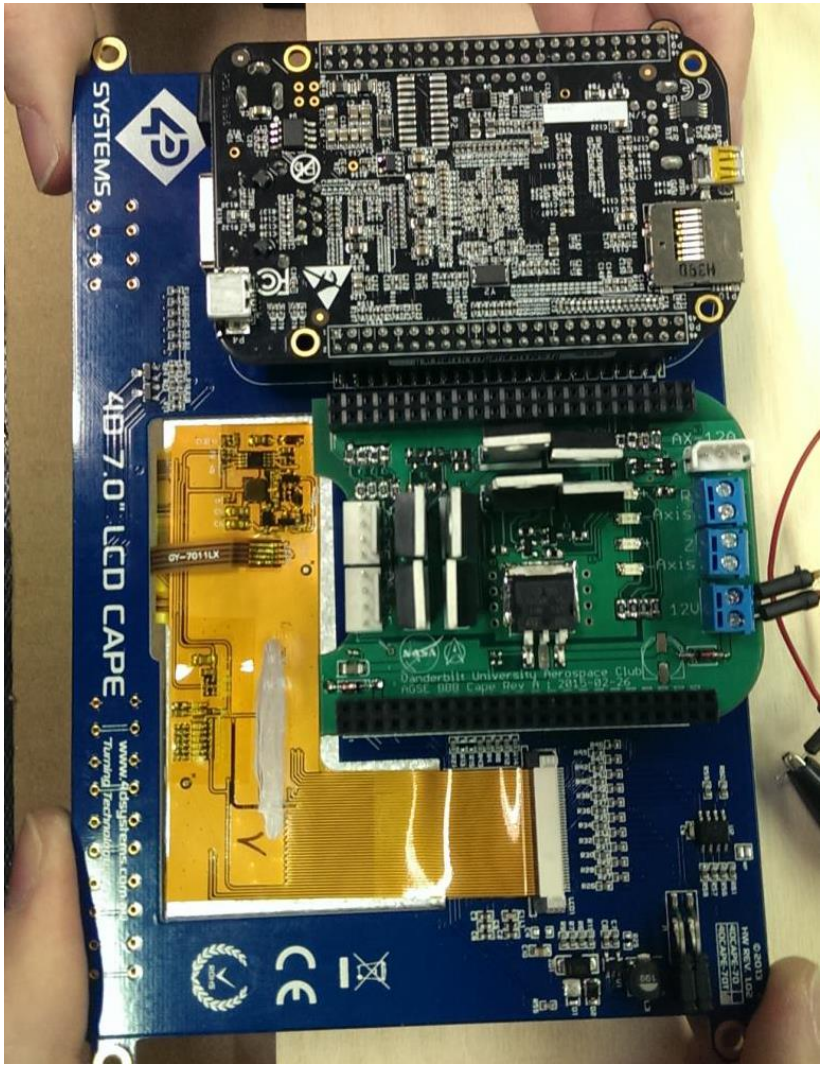
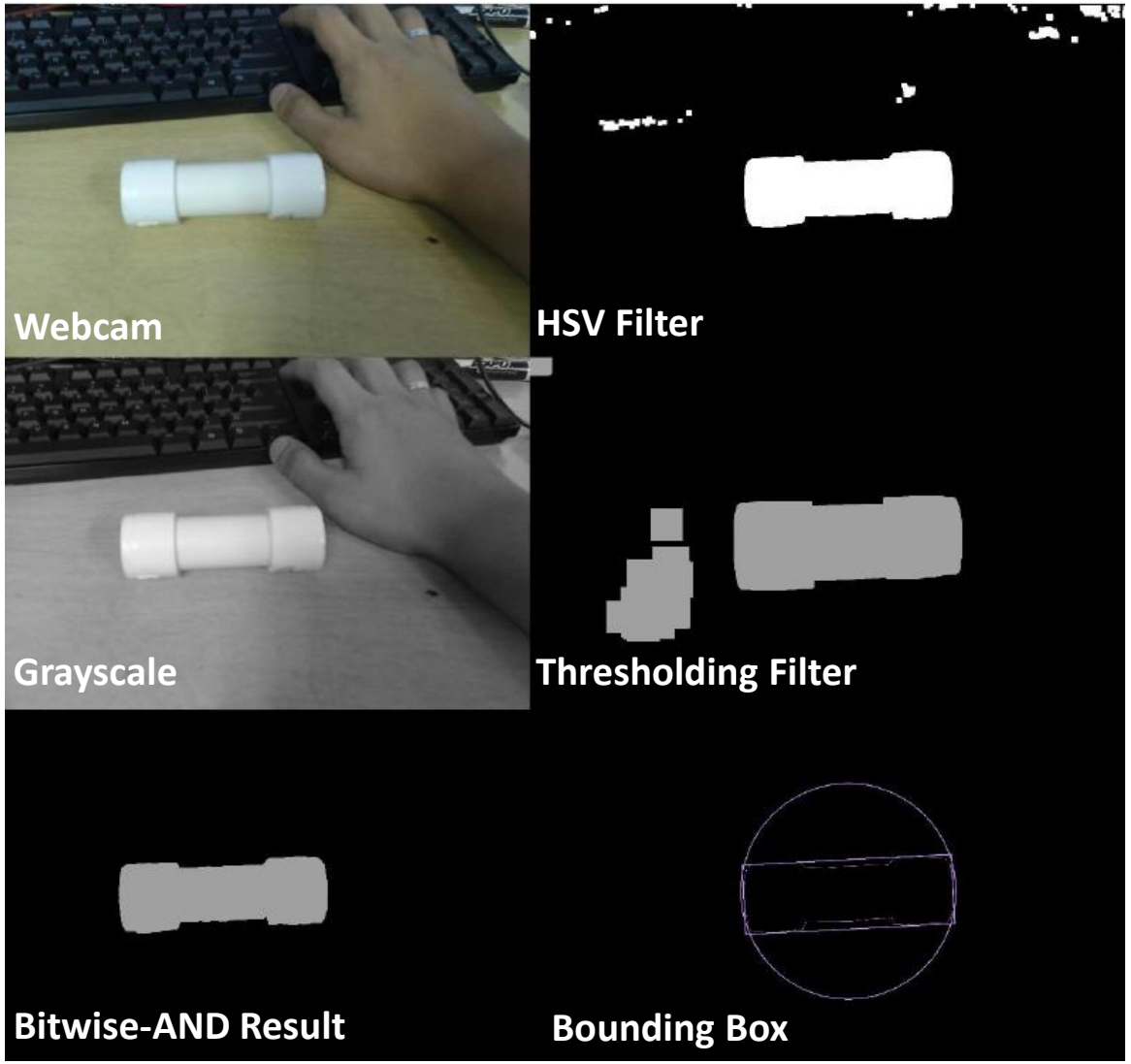


Image Processing – Sample Detection

- OpenCV software library
- Computer vision to classify and track observed objects in real-time
- Periodic Processing
  - Convert RGB image frame to HSV/Grayscale image frame
  - Apply thresholding, filtering, erosion and dilation procedures
  - Draw contours around detected objects
  - Calculate position & relative orientation

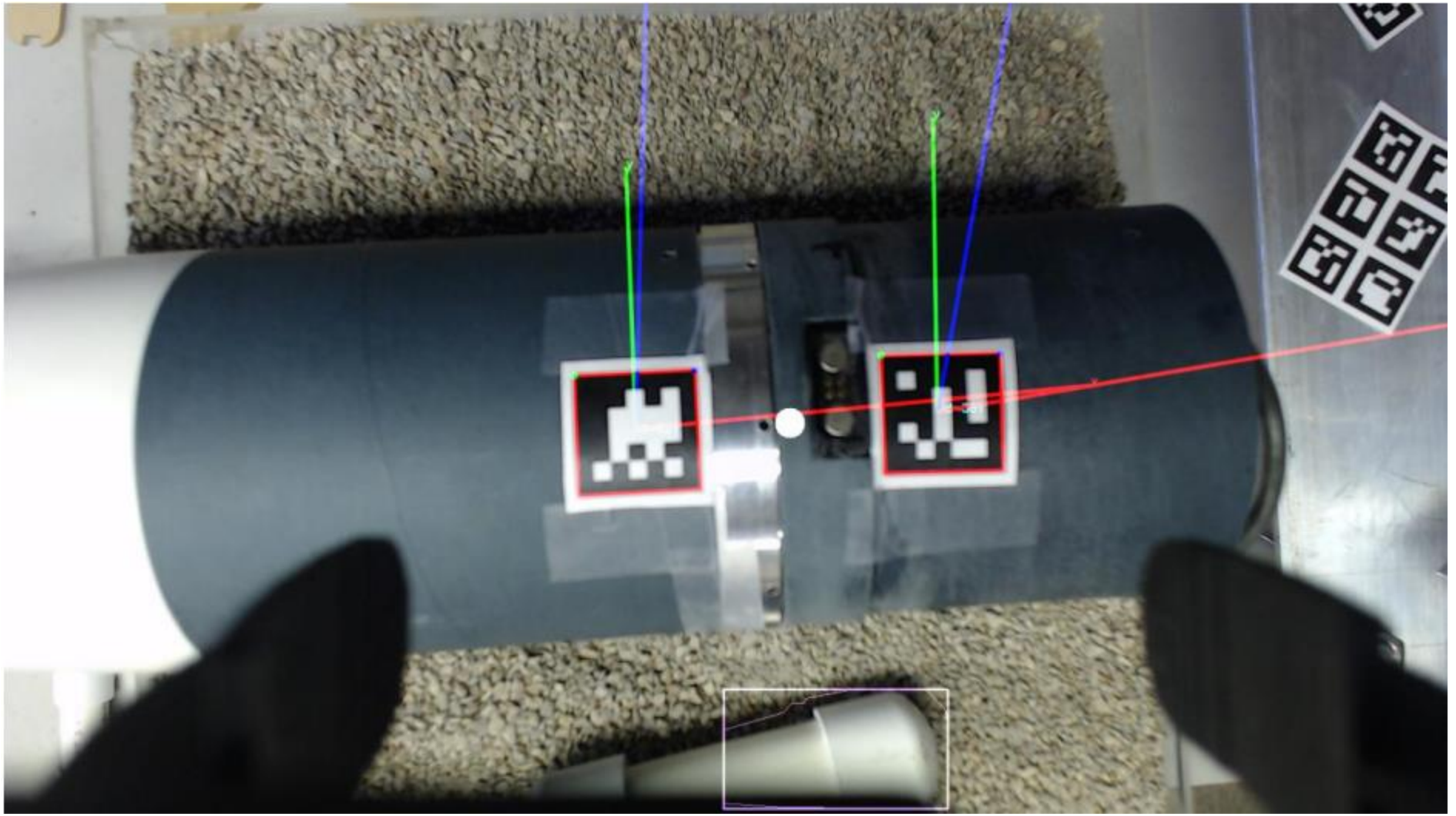
Real-time Object Tracking



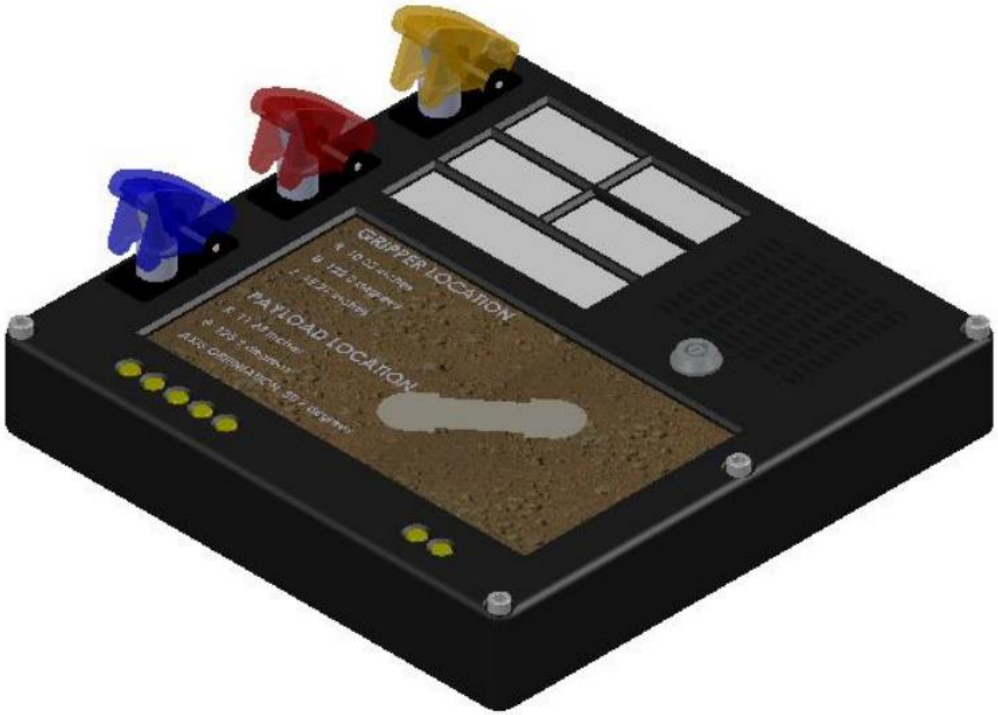
Feature-based Filtering Heuristics

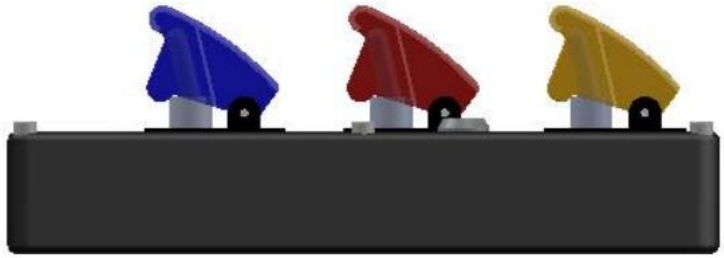
Multiple Sample Detection

Payload Bay Detection



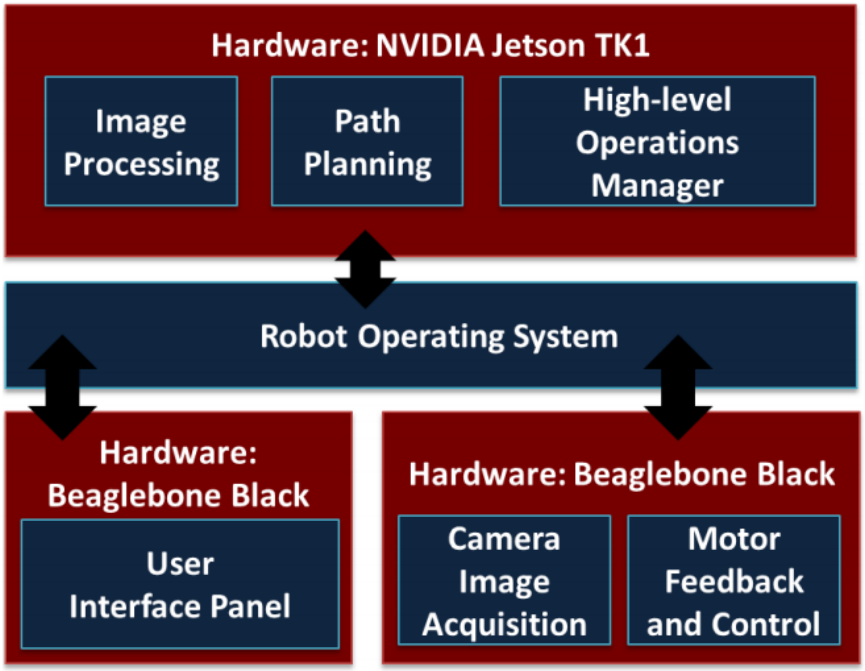
User Input Panel

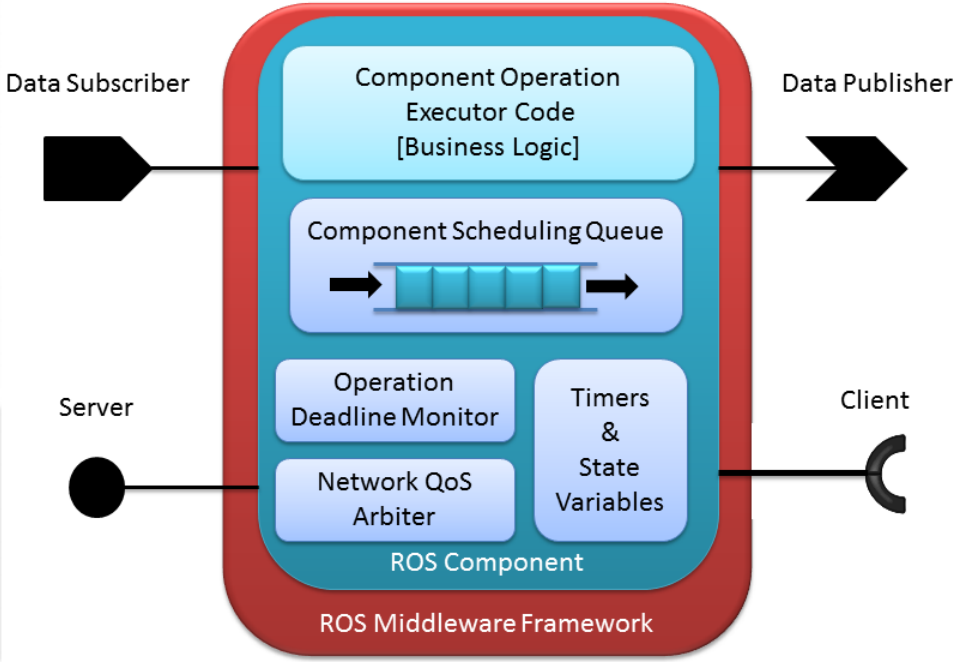




Software Development
Robot Operating System & ROSMOD

- Distributed Embedded System
- Use Robot Operating System
  - ROSMOD Component Model
  - Modeling, Code Generation & Deployment tool suite





ROSMOD Projects

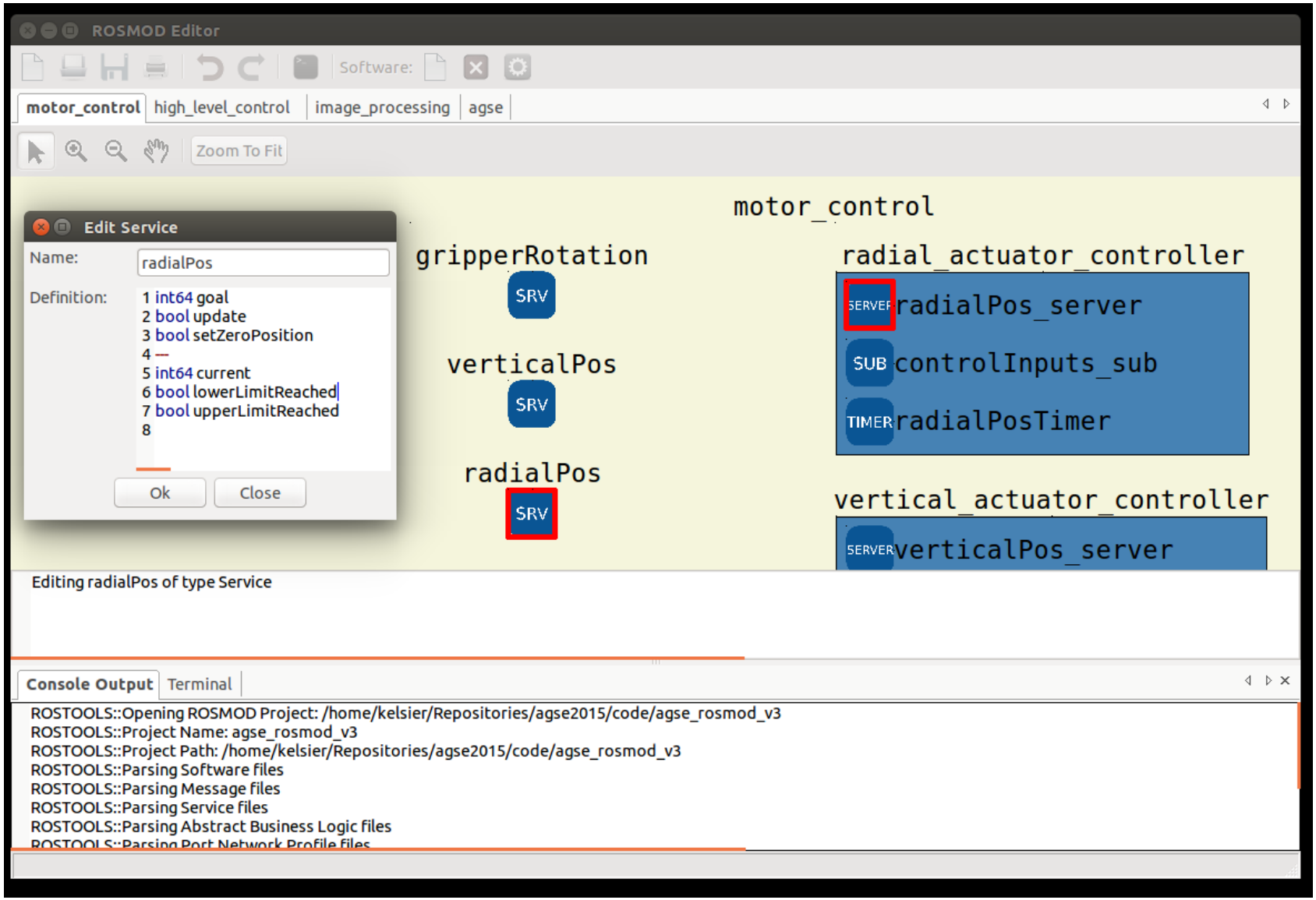
- Software Workspace Model
  - Messages, Services & Component definitions
  - *Workspace & build system generation*
- Hardware Model
  - IP Address, Architecture & network topology
- Deployment Model
  - Process-to-Hardware mapping
  - Component Instantiation in processes
  - *Deployment-specific XML Generation*

Textual Language

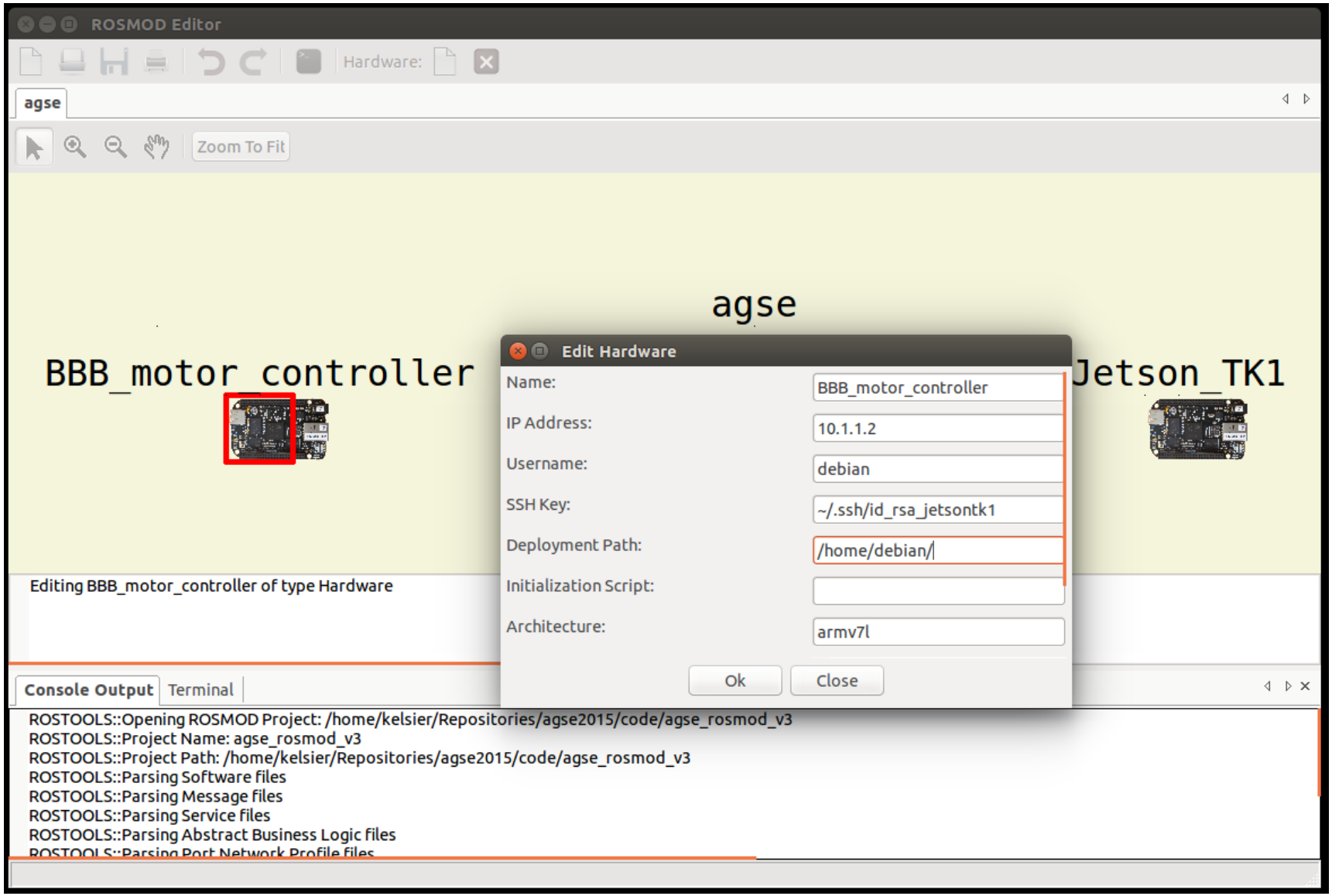
```
/*
 * ROSMOD Software Model
 */

// ROSMOD Package - motor_control
package motor_control
{
  // ROSMOD Component - radial_actuator_controller
  component radial_actuator_controller : Base
  {
    // ROSMOD Server - radialPos_server
    server <motor_control/radialPos> radialPos_server
    {
      priority = 50;
      deadline = 0.1;
    }
    // ROSMOD Subscriber - controlInputs_sub
    subscriber <high_level_control/controlInputs> controlInputs_sub
    {
      priority = 50;
      deadline = 0.1;
    }
    // ROSMOD Timer - radialPosTimer
    timer radialPosTimer
    {
    period = 0.01;
    priority = 50;
    deadline = 0.01;
    }
  }
  // ROSMOD Component - vertical_actuator_controller
  component vertical_actuator_controller : Base
  {
    // ROSMOD Server - verticalPos_server
    server <motor_control/verticalPos> verticalPos_server
    {
      priority = 50;
      deadline = 0.1;
    }
    // ROSMOD Subscriber - controlInputs_sub
    subscriber <high_level_control/controlInputs> controlInputs_sub
    {
```

```
/*
 * ROSMOD Hardware Model
 */

// Hardware - BBB_motor_controller
hardware BBB_motor_controller
{
  ip_address = "10.1.1.2";
  username = "debian";
  sshkey = "~/.ssh/id_rsa_jetsontk1";
  deployment_path = "/home/debian/";
  arch = armv7l;
}
// Hardware - BBB_user_input
hardware BBB_user_input
{
  ip_address = "10.1.1.3";
  username = "debian";
  sshkey = "~/.ssh/id_rsa_jetsontk1";
  deployment_path = "/home/debian";
  arch = armv7l;
}
// Hardware - Jetson_TK1
hardware Jetson_TK1
-:---  agse.rhw       Top L8    Git-master  (Antlr.Java/l)
/*
 * ROSMOD Deployment Model
 */

// ROSMOD Hardware Model - agse
using agse;

// ROSMOD Node - arm
node arm
{
  properties
  {
    ref = "agse/Jetson_TK1";
    priority = 50;
  }
  component_instance arm_controller_i
  {
```

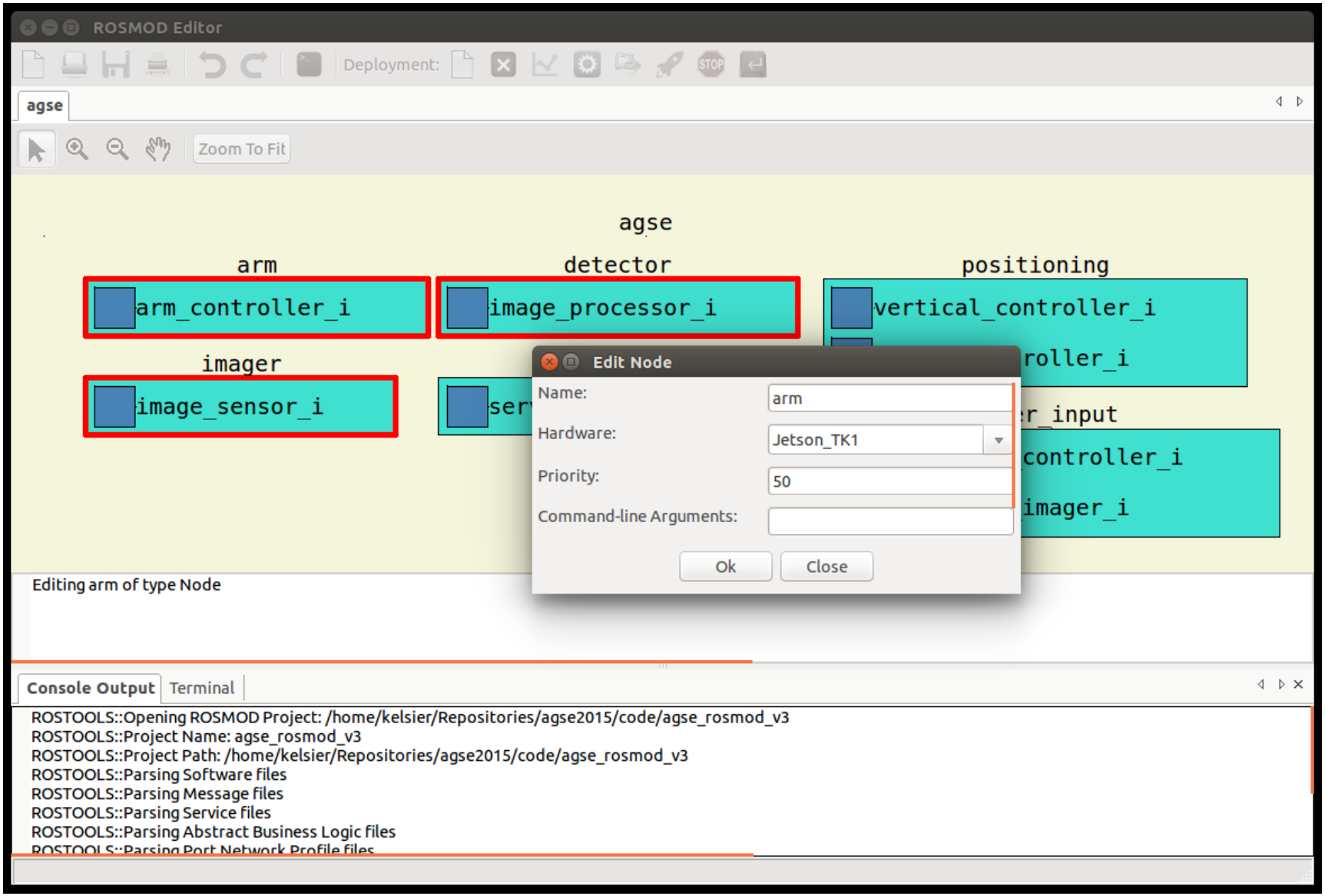
ROSMOD Editor – Software Model



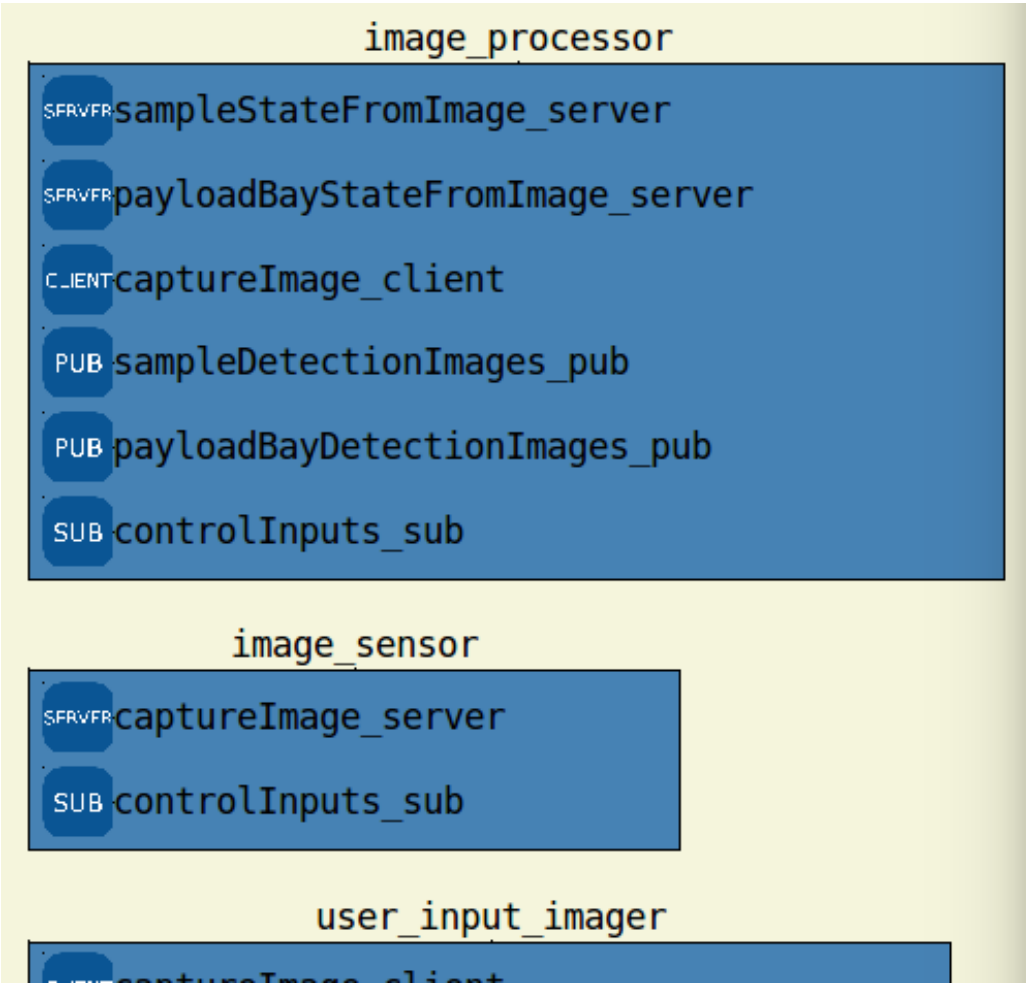
ROSMOD Editor – Hardware Model



ROSMOD Editor – Deployment Model



Workspace Code Generation




```
└── src
    ├── image_processing
    │   ├── CMakeLists.txt
    │   ├── include
    │   │   └── image_processing
    │   │       ├── Component.hpp
    │   │       ├── image_processor.hpp
    │   │       ├── image_sensor.hpp
    │   │       ├── Logger.hpp
    │   │       ├── rapidxml.hpp
    │   │       ├── rapidxml_utils.hpp
    │   │       ├── user_input_imager.hpp
    │   │       └── xmlParser.hpp
    │   ├── msg
    │   │   ├── payloadBayDetectionImages.msg
    │   │   └── sampleDetectionImages.msg
    │   ├── package.xml
    │   ├── src
    │   │   └── image_processing
    │   │       ├── Component.cpp
    │   │       ├── image_processor.cpp
    │   │       ├── image_sensor.cpp
    │   │       ├── Logger.cpp
    │   │       └── user_input_imager.cpp
    │   └── srv
    │       ├── captureImage.srv
    │       ├── payloadBayStateFromImage.srv
    │       └── sampleStateFromImage.srv
```

Generated Skeleton Code

```
class image_processor : public Component
{
public:
  // Constructor
  image_processor(ComponentConfig& config, int argc, char **argv) : Component(config, argc, argv) {}

  // Initialization
  void Init(const ros::TimerEvent& event);

  // Subscriber Callback - controlInputs_sub
  void controlInputs_sub_OnOneData(const high_level_control::controlInputs::ConstPtr& received_data);

  // Server Callback - sampleStateFromImage_server
  bool sampleStateFromImageCallback(image_processing::sampleStateFromImage::Request &req,
    image_processing::sampleStateFromImage::Response &res);

  // Server Callback - payloadBayStateFromImage_server
  bool payloadBayStateFromImageCallback(image_processing::payloadBayStateFromImage::Request &req,
    image_processing::payloadBayStateFromImage::Response &res);

  // Start up
  void startUp();

  // Destructor
  ~image_processor();

private:

  // Subscriber
  ros::Subscriber controlInputs_sub;

  // Publisher
  ros::Publisher sampleDetectionImages_pub;

  // Publisher
  ros::Publisher payloadBayDetectionImages_pub;

  // Server
  ros::ServiceServer sampleStateFromImage_server;

  // Server
  ros::ServiceServer payloadBayStateFromImage_server;

  // Client
  ros::ServiceClient captureImage_client;
```

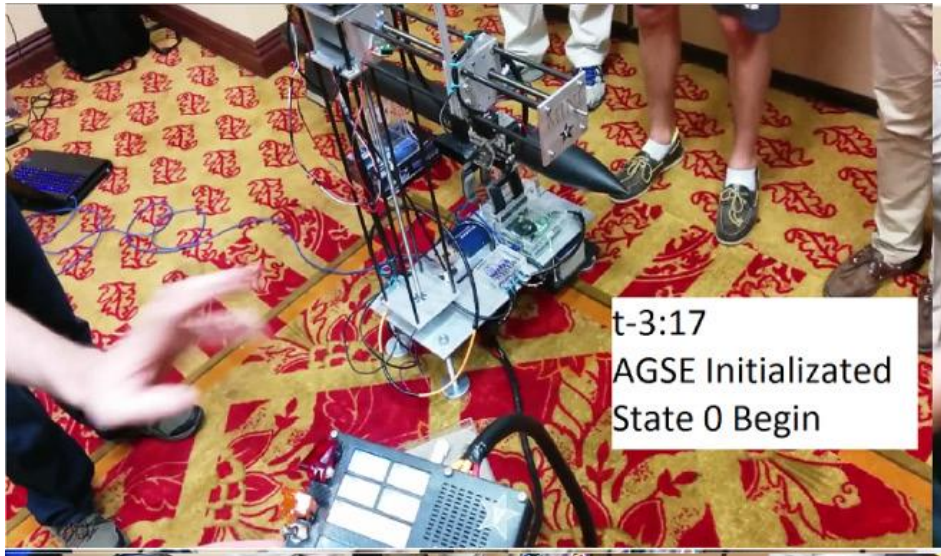
-:--- image_processor.hpp 27% L26 (C++/l Abbrev)

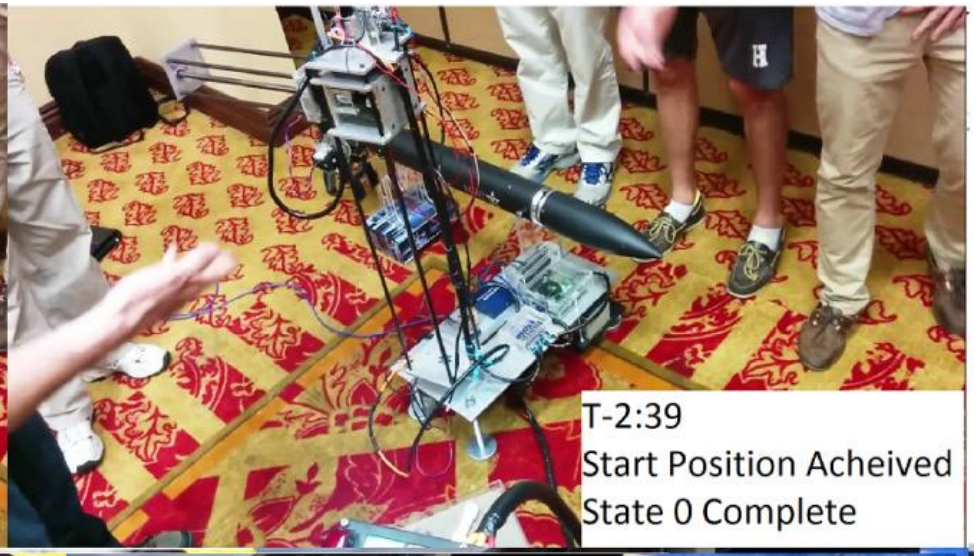
```
//# Start User Globals Marker
//# End User Globals Marker

// Initialization Function
//# Start Init Marker
void image_processor::Init(const ros::TimerEvent& event)
{
  // Initialize Here

  // Stop Init Timer
  initOneShotTimer.stop();
}
//# End Init Marker

// Subscriber Callback - controlInputs_sub
//# Start controlInputs_sub_OnOneData Marker
void image_processor::controlInputs_sub_OnOneData(const high_level_cont
 received_data)
{
  // Business Logic for controlInputs_sub Subscriber
}
//# End controlInputs_sub_OnOneData Marker

// Server Callback - sampleStateFromImage_server
//# Start sampleStateFromImageCallback Marker
bool image_processor::sampleStateFromImageCallback(image_processing::sa
&req,
  image_processing::sampleStateFromImage::Response &res)
{
  // Business Logic for sampleStateFromImage_server Server

  return true;
}
//# End sampleStateFromImageCallback Marker
// Server Callback - payloadBayStateFromImage_server
//# Start payloadBayStateFromImageCallback Marker
bool image_processor::payloadBayStateFromImageCallback(image_processing
equest  &req,
  image_processing::payloadBayStateFromImage::Response &res)
{
  // Business Logic for payloadBayStateFromImage_server Server

  return true;
}
//# End payloadBayStateFromImageCallback Marker


// Destructor - Cleanup Ports & Timers
```

-:--- image_processor.cpp Top L44 (C++/l Abbrev)

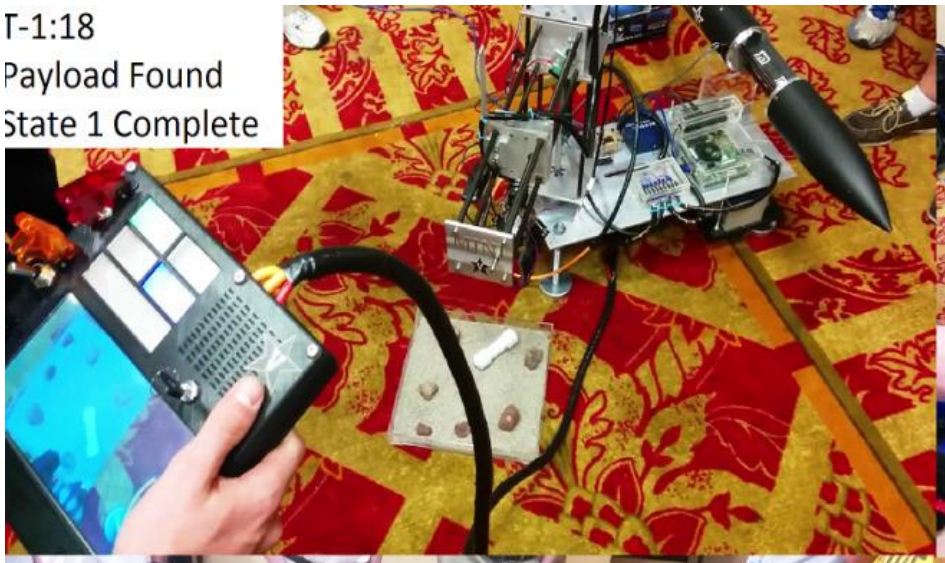
Beginning of buffer

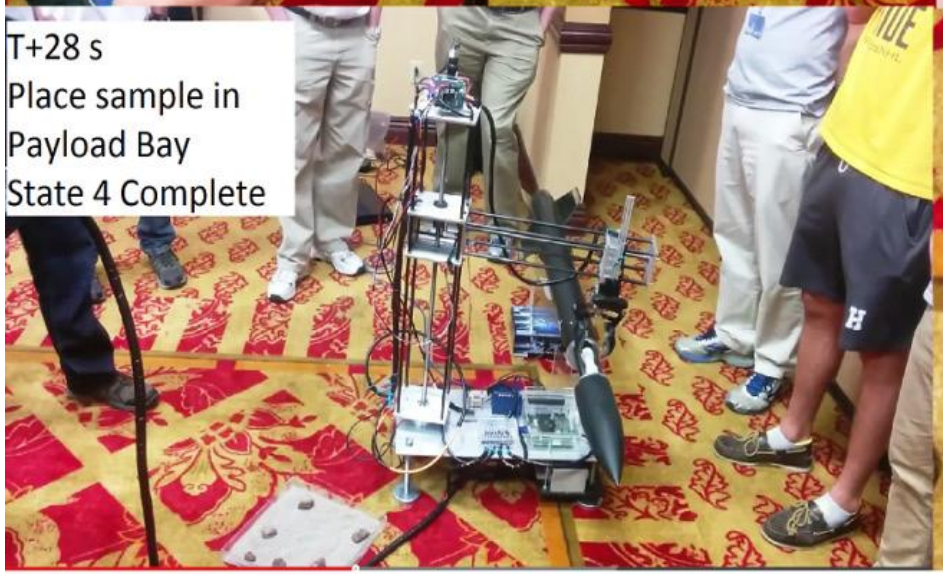
Performance Assessment





Performance Assessment





Summary

- Model-driven Component-based Engineering
- Distributed Managed Embedded System
- Robot Operating System & ROSMOD
- Autonomous Sample Retrieval
  - Periodic Image Processing
  - Unknown Sample & Rocket location
  - Under 5 minutes on Competition Day
- We won ☺

Vanderbilt Aerospace Club 2014-2015