Developing a Gstreamer-Based Custom Camera System for Long-Range Biometric Data Collection

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Background

IARPA BRIAR:

Biometric **R**ecognition and **I**dentification at **A**ltitude and **R**ange

Challenging imaging conditions:

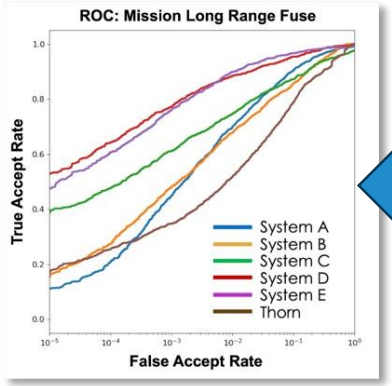
- Atmospheric distortion
- Camera motion

Existing algorithms:

- Are trained on low-angle, close-range data
- Rely on face recognition as the only biometric modality

ORNL's role: data collection and T&E

Oak Ridge National Laboratory's Role as BRIAR T&E Lead



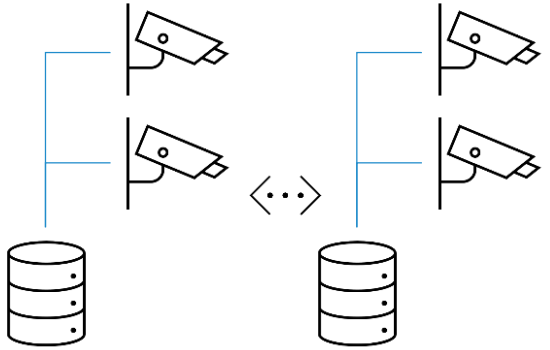
Testing and evaluation of performer team recognition models

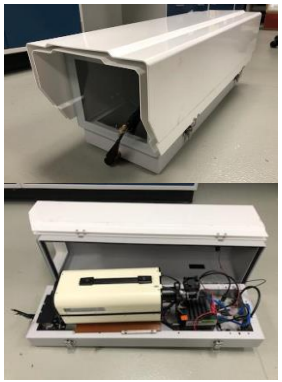
Experiment design, subject recruiting, dataset collection, curation, and annotation

Engineering and integration of support technology, cameras, and equipment

Custom Cameras Use-Case: Specialized Data Collection

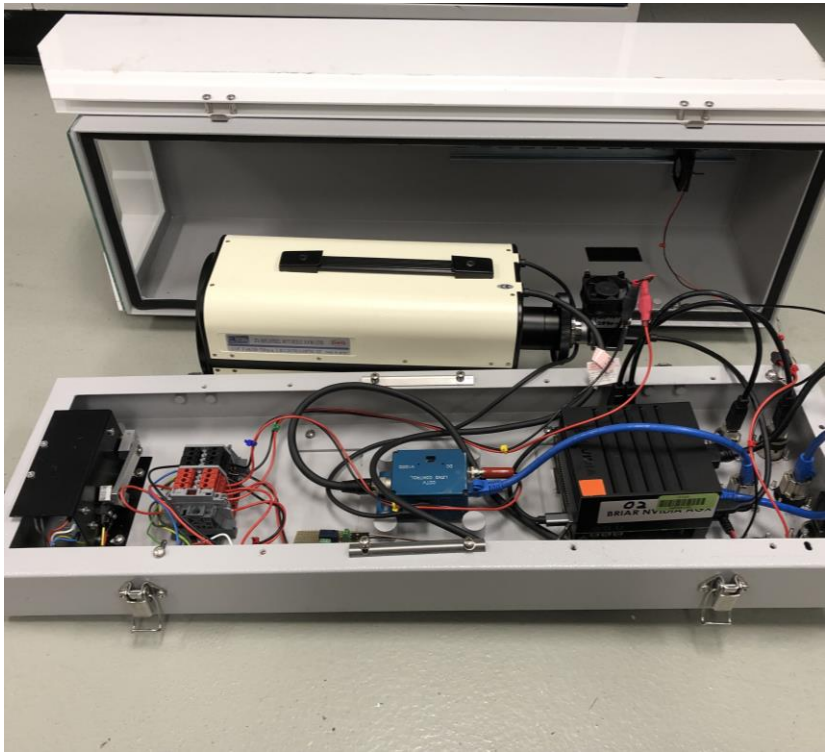
- Integration with commercial surveillance infrastructure: dozens of IP cameras, network video recorders at stations 5 m to 1 km from subject area(s)
- Interchangeable optics and sensors
- Network streaming and control of multiple custom cameras
- Raw capture recording





BRIAR Specialized Camera

- Nvidia Jetson AGX
- Basler Ace sensors
- High power lenses
- Control hardware (lens-specific)
- Weatherproof enclosure
- Mounting hardware for tripods, pan/tilt positioners, etc.

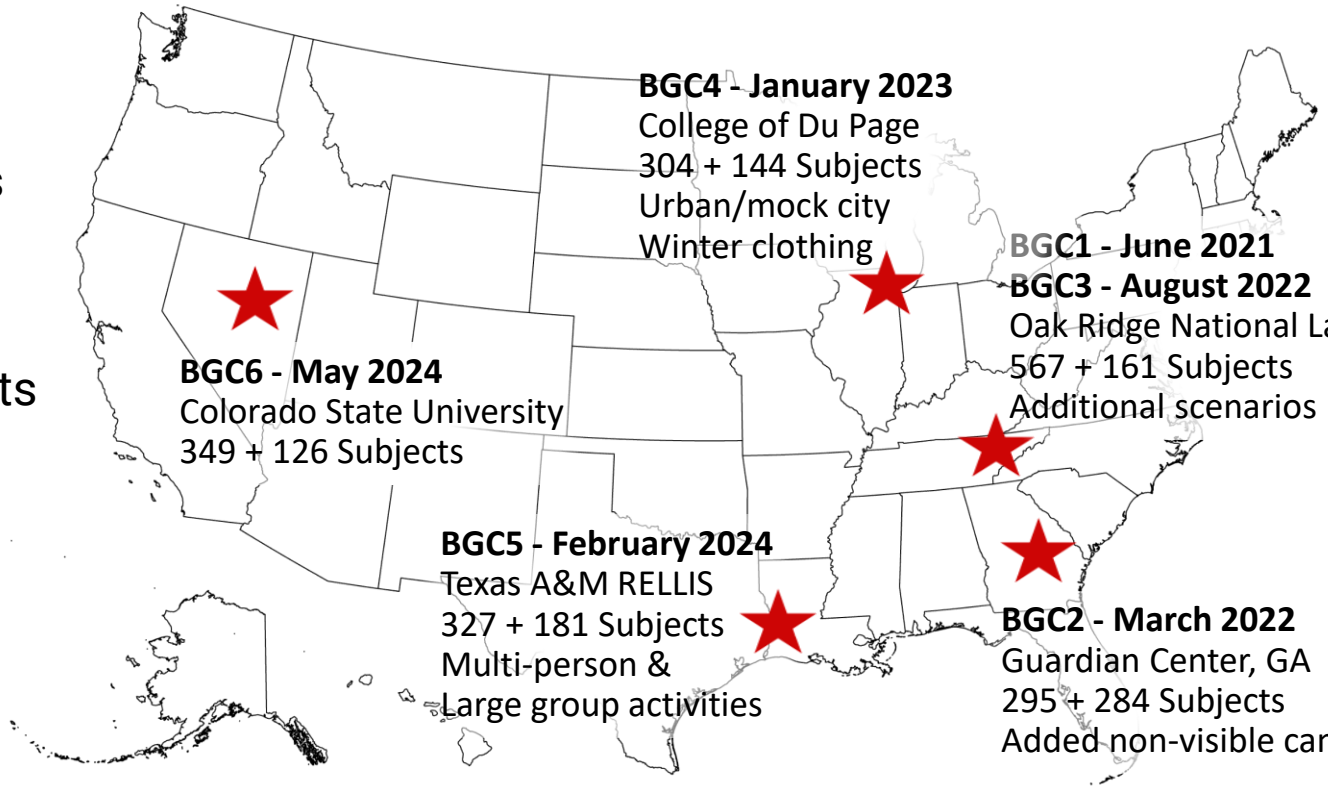


Collection Details

1842 Full Subjects

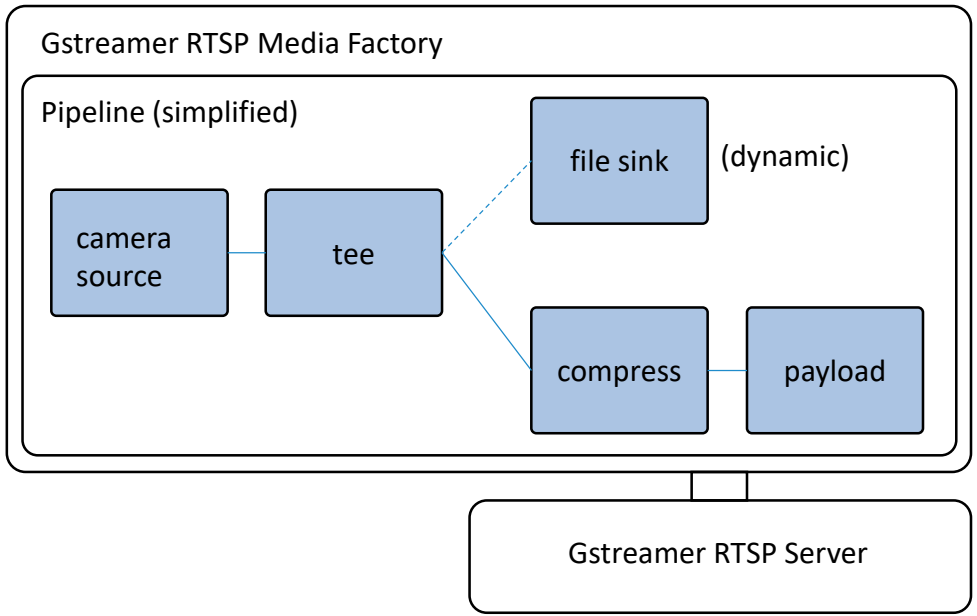
896 Indoor Only

2738 Total Subjects



Why Gstreamer?

- C-based framework for pipelines of data sources, filters, and sinks
- Extensive libraries of plugins implement additional elements
- Built on top of GLib (for main loop abstraction and data types) and GObject (OOP shoehorned into C)
- Dynamic pipelines are edited with callbacks triggered by signals, timers, or probed data

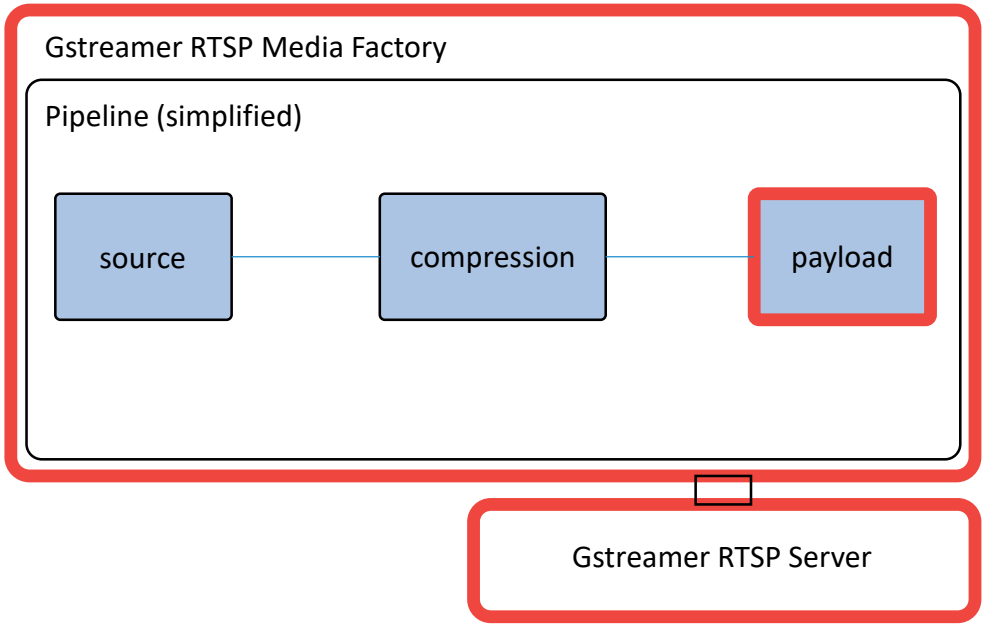


RTSP Streaming - GstRTSPServer

- The server signals a media factory object to create its pipeline when an RTSP client sends a request

`rtsp://<ip_address>:8554/<tag>`

- The `<tag>` is associated with a specific media factory
- Once the pipeline is running, the server streams the payload output over RTSP



GstRTSPServer – Pipeline Creation on Client Request

- The media factory creates and links pipeline elements from the description in `pipeline_string`

- The `media-configure` signal triggers a user-defined callback to perform any pipeline configuration or additional actions needed

```
// ----------  Set up RTSP ----------

GstRTSPServer *rtsp_server;
GstRTSPMountPoints *rtsp_mount_points;
GstRTSPMediaFactory *rtsp_media_factory;

rtsp_server = gst_rtsp_server_new();
gst_rtsp_server_set_address(rtsp_server, control_data->RTSPaddress);
rtsp_mount_points = gst_rtsp_server_get_mount_points(rtsp_server);
rtsp_media_factory = gst_rtsp_media_factory_new();
gst_rtsp_media_factory_set_launch(rtsp_media_factory, pipeline_string);
gst_rtsp_media_factory_set_shared(rtsp_media_factory, TRUE);
g_signal_connect(rtsp_media_factory, "media-configure",
    (GCallback)media_configure, (gpointer) &pipeline_data);
// EX: rtsp://127.0.0.1:8554/config1_acA2040-120uc
gchar *mount_point_str = g_strdup_printf("/%s_%s", metadata->name, sensor_setup_info->name);
gst_rtsp_mount_points_add_factory(rtsp_mount_points, mount_point_str, rtsp_media_factory);
g_object_unref(rtsp_mount_points);
guint rtsp_server_id = gst_rtsp_server_attach(rtsp_server, NULL);

timestamp_prefix_log();
g_print("RTSP server ready at rtsp://%s:8554%s\n", control_data->RTSPaddress, mount_point_str);
```

System Configuration

- JSON files: `config.json` and `sensor.json`
  - Set important metadata, as well as system, network, sensor, and peripheral hardware settings
  - These files are read into structs using cJSON on startup
- Text file: `pipeline.txt`
  - Creative string formatting for pipeline configuration
  - Minor changes without recompile

```
{
    "Metadata":
    {
        "Name":             "config1",
        "Location":         "field",
        "Range":            500,
        "Yaw":              12,
        "Elevated":         false,
        "Lens Name":        "Sigma 600",
        "Focal Length":     600,
        "Collection ID":    "BGC6"
    },
    "Control Data":
    {
        "Record Raw":               true,
        "Raw Storage":              "/data/briar_rec",
        "Control IP":               "127.0.0.1",
        "Control Port":             9000,
        "Status Broadcast Port":    9001,
        "Raw Time Limit":           600,
        "RTSP Address":             "127.0.0.1",
```

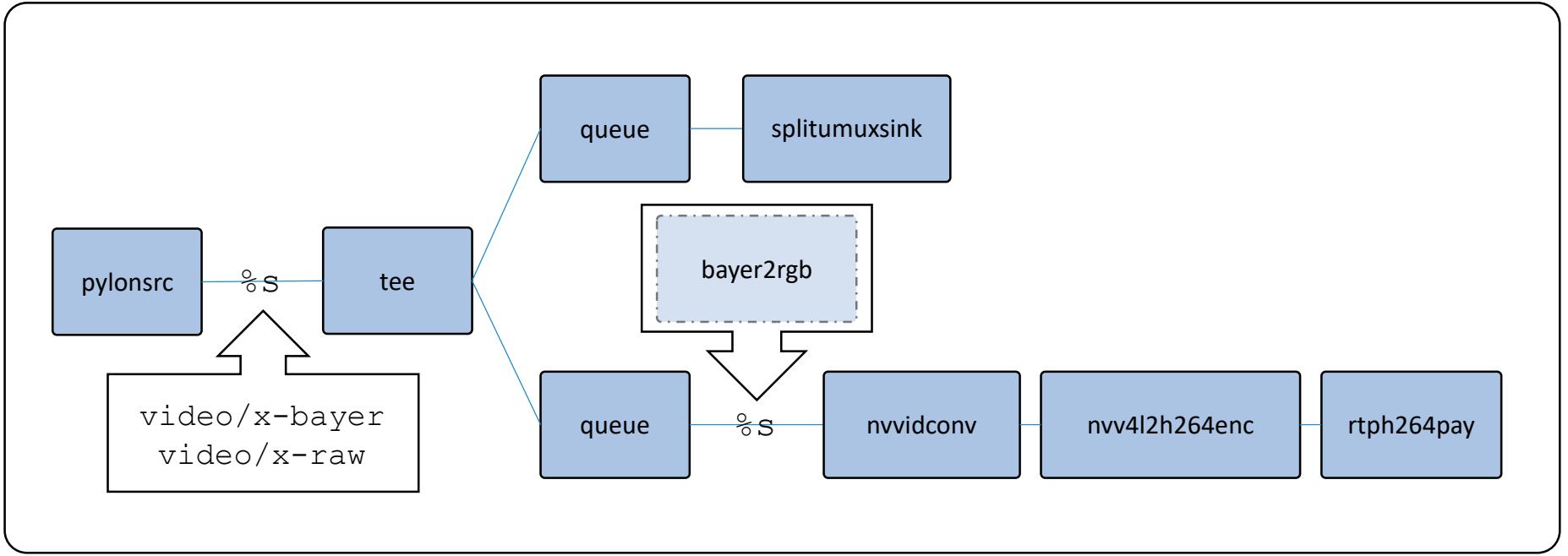
A Gstreamer Pipeline Description (a mess, but bear with me…)

```
pylonsrc name=source ! %s !

tee name=t ! queue name=raw_queue !

splitmuxsink name=sink muxer=identity
location=/dev/null

t. ! queue name=rtsp_queue !%s
nvvidconv name=converter !

video/x-raw(memory:NVMM),
format=I420,framerate=30/1 !

nvv4l2h264enc bitrate=20000000 !
h264parse !

rtph264pay name=pay0
```

- Gst-plugin-pylon camera source element*
- Tees and Queues abstract multithreading
- `splitmuxsink` element for timed/toggled local recording
- Second branch of the tee is used for RTSP stream, format converted*
- Capabilities or “Caps” describe data frames and transmission between elements
- Nvidia-specific hardware encoder element encodes video stream to h264. Data buffers are parsed into packets
- Payload element exposes stream to GstRTSPServer

*** `%s` -- C string formatting; caps and element insertion based on sensor characteristics**

Pipeline Description



Basler gst-plugin-pylon

- **pylonsrc:** Gstreamer source element plugin for all Basler 2D cameras
- All camera features exposed as gstreamer properties
- We used color and mono sensors as well as a variety of resolutions and formats
- **Issues with the beta versions**: broken cleanup of camera elements, difficulties getting/setting effective resolutions
- v1.0.0 released Aug ’24, but throughout development and field-use we were working with v0.5.1 through v0.7.0

Sensor Setup: It's not a bug, it's a feature!

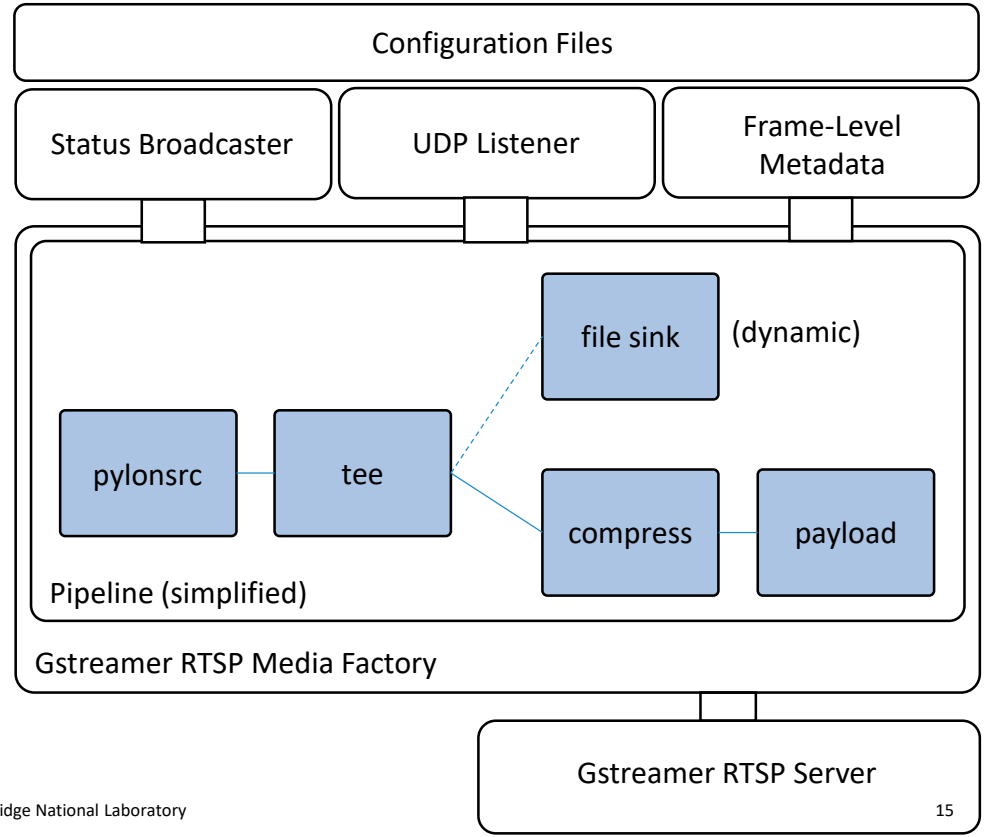
- `sensor_setup` – separate executable run any time a new sensor was added
- Workaround for gst-plugin-pylon beta version bugs
- Writes JSON configuration file with editable sensor settings

```
{
    "Model":          "acA2040-90um",
    "Serial Number":"00000000",
    "Caps Type":      "video/x-raw",
    "Color Filter":  "GRAY",
    "Width":          2048,
    "Height":         2048,
    "Exposure Time":1000,
    "Gain":           3,
    "Auto Exposure":"AUTO_ONCE",
    "Auto Gain":      "AUTO_OFF"
}
```

```
SensorSetupInfo *loadSensorSetupInfo(void) {
    /*
    Load sensor information from a JSON file written by
    writeSensorSetupJSON.
    Returns a SensorSetupInfo struct with a fully formatted caps string
    for the gstreamer pipeline
    */
```

Application Interfaces

- Status Broadcaster: sends system information over UDP
- UDP Listener: handles incoming messages to toggle raw recordings, change sensor settings
- Frame-Level Metadata: probes the frame buffers moving through the pipeline for detailed info, uses another gstreamer pipeline to write to CSV files.



“media-configure” and Useful Callbacks

`g_signal_connect:` attach a callback to a specific signal

- In this case, the callback changes the path of the recording file that `splitmuxsink` element writes

`g_io_add_watch:` attach a callback to some I/O action

- In this case, the callback processes incoming UDP messages

```
130     // get the raw recording elements if they exist
131     if (pipeline_data->control_data->recordRaw) {
132         pipeline_data->sink =

// allow the location of the splitmuxsink to be changed by signal
g_signal_connect(pipeline_data->sink, "format-location",
    (GCallback)format_recording_filepath, pipeline_data);

139         pipeline_data->raw_queue =
140             gst_bin_get_by_name_recurse_up(GST_BIN(media_bin), "raw_queue");
141     } else {
142         pipeline_data->sink = NULL;
143         pipeline_data->raw_queue = NULL;
144     }

// listen for incoming UDP packets
pipeline_data->udp_channel_watch_id =
    g_io_add_watch(pipeline_data->udp_channel, G_IO_IN,
    (GIOFunc)udp_received_callback, pipeline_data);

152     get filepaths for the sensor and frame-level metadata
153     then create those files
154     */
155     char *recording_dir = NULL;
156     if (format_recording_directory(pipeline_data->control_data, &recording_di
157         timestamp_prefix_err();
```

“media-configure” and Useful Callbacks

`g_timeout_add_seconds`:
execute a timed callback

- Used to enforce a time limit on local recordings and metadata files

`gst_pad_add_probe`: access data buffers at an input/output of an element

- Access/record frame-level metadata while pipeline plays

```
203     // start the file limit timer
        pipeline_data->file_limit_callback_id =
            g_timeout_add_seconds(time_limit,
            (GSourceFunc) file_limit,
            (gpointer) pipeline_data);
211     frame_metadata_filepath = NULL;
212
213     // install the frame-level metadata probe at the source element
        src_pad = gst_element_get_static_pad(pipeline_data->source, "src");
        pipeline_data->metadata_probe_id =
            gst_pad_add_probe(src_pad, GST_PAD_PROBE_TYPE_BUFFER,
            (GstPadProbeCallback) frame_level_metadata,
            (gpointer) pipeline_data,
            (GDestroyNotify) metadata_cleanup);
```

Peripheral Hardware Interfaces: Lens Control

Standardized Description

UDP listener settings defined in `config.json`

```
"Name":             "ISSI Focus Controller",
"Filepath":         "hardware/issi_focus_control.py",
"Listener Port":    "7925",
"Device IP":        "192.168.2.252",
"Device Port":      "1339",
"Capabilities": [
    {
        "Name": "Focus",
        "Commands":["+", "++", "-", "--"]
    }
]
```

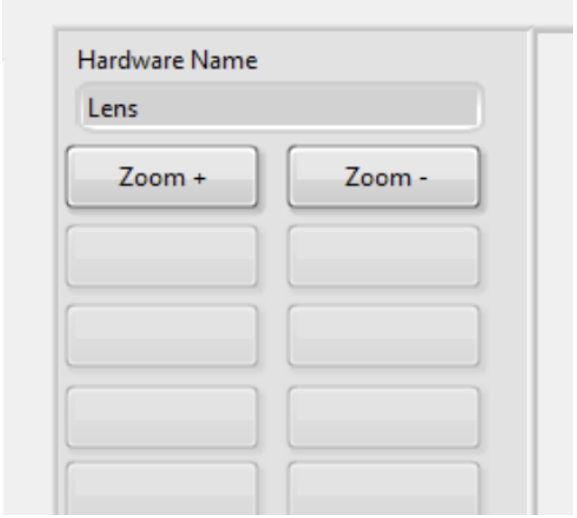
Python Subclassing

Device specific implementation, e.g., network device, GPIO

```
from interface import HardwareInterface

class ISSIFocusControl(HardwareInterface):
    """Implements the EF-lens focus control

    capabilities = {
        "Focus":["+", "++", "-", "--"],
    }

    def __init__(self, *args, **kwargs):
        super().__init__(*args, **kwargs)

        self.step_size = 50

    def Focus(self, arg):
        if arg == "+":
```

Status Broadcast

JSON informs monitoring and control GUI.



Conclusions

Challenges

- Choosing the correct elements for the hardware and application
- Configuring a dynamic pipeline within an RTSP Server

Lessons Learned

- Stress testing should be *really* stressful

Insights and Advice

- It'll take longer than you think
- Friends and documentation
- Don't be afraid of workarounds

Cameras in the Wild!

Resources/Links

Oak Ridge National Laboratory	https://www.ornl.gov/
IARPA – BRIAR Home Page	https://www.iarpa.gov/research-programs/briar
Gstreamer Homepage	https://gstreamer.freedesktop.org/
Basler gst-pylon-plugin	https://github.com/basler/gst-plugin-pylon
cJSON	https://github.com/DaveGamble/cJSON

ORNL Open Source: https://github.com/ornl

Open-source license approval in progress at time of submission…