Teleoperated Robot Control With Augmented Reality

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Background

- Jaguar 4x4 robots from Dr. Robot with:
  - High durability, video/audio feed, sensor information, robotic arm, Wi-Fi communication
- Optimal for:
  - Military reconnaissance and bomb defusal
  - Reconnaissance and object manipulation for police and firefighters

Problem:

- Want one device to control robot and view information with minimal encumbrance, distortion, and occlusion

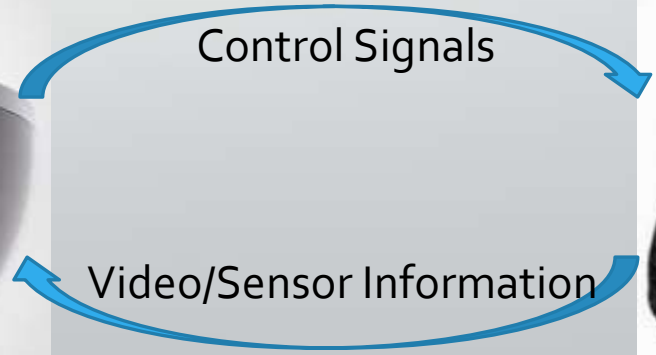
Existing Solutions

- **Viewing video and sensor information**
  - Laptop
    - Requires user to carry a laptop around
  - Heads up display from Dr. Robot
    - Opaque display that distorts real world
    - No control
- **Control**
  - Video game controller
    - Ties up users hands
  - Microsoft Kinect
    - Requires carrying a Kinect camera around
    - Doesn't work in bright sunlight

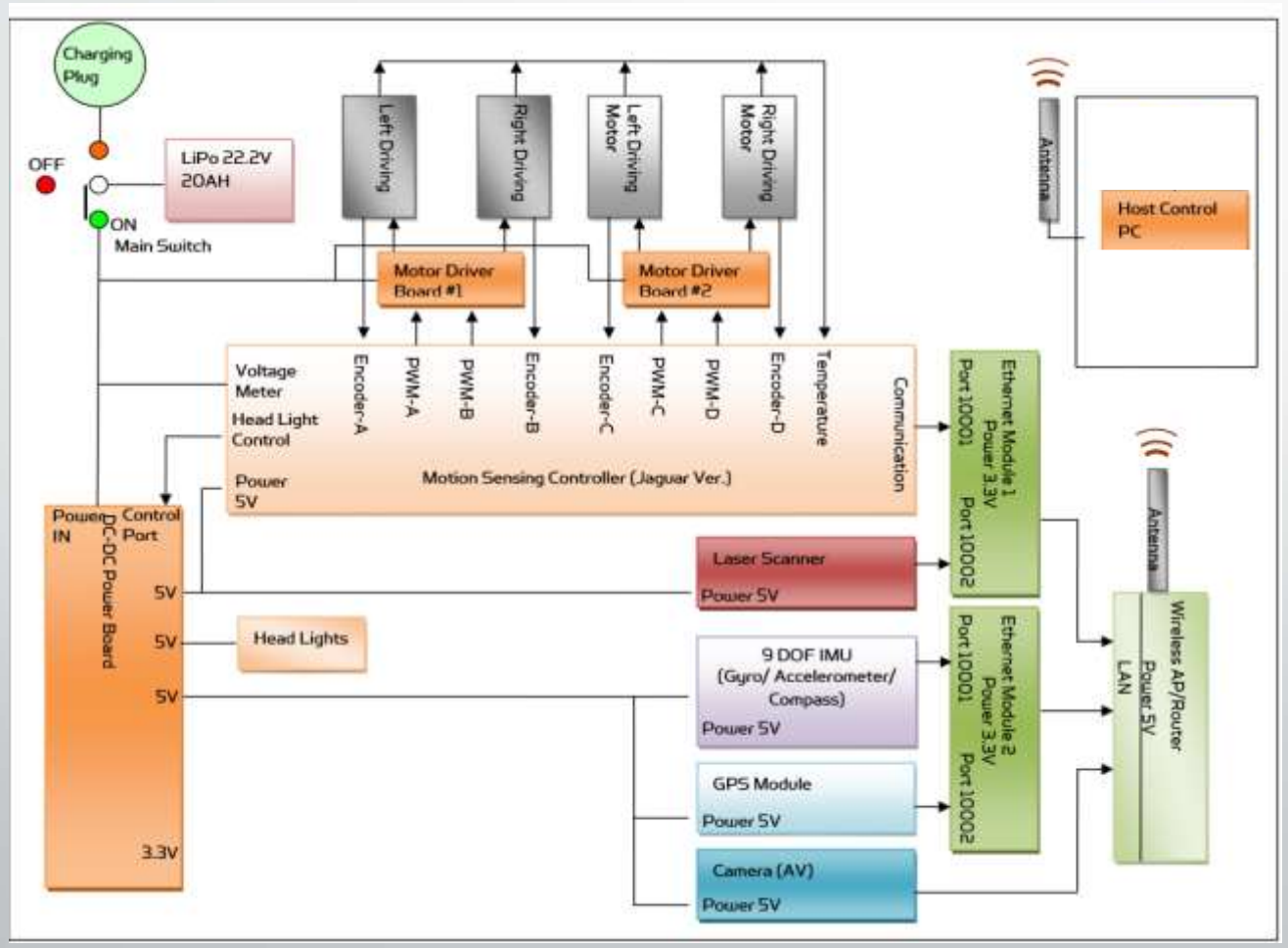
Solution

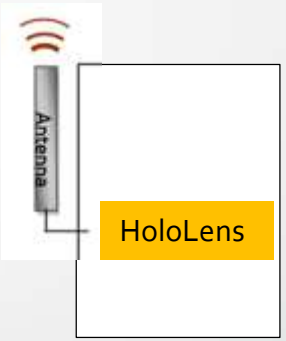
- Microsoft HoloLens to control robot and view information
  - Augmented reality display
    - Wireless
    - Sensor information constantly visible
    - Transparent Head-Mounted Display (hands free)
    - Already owned by the university
  - Variety of input options
    - Hand gestures
    - Voice
    - Clicker

Top Level Design



Hardware block diagram

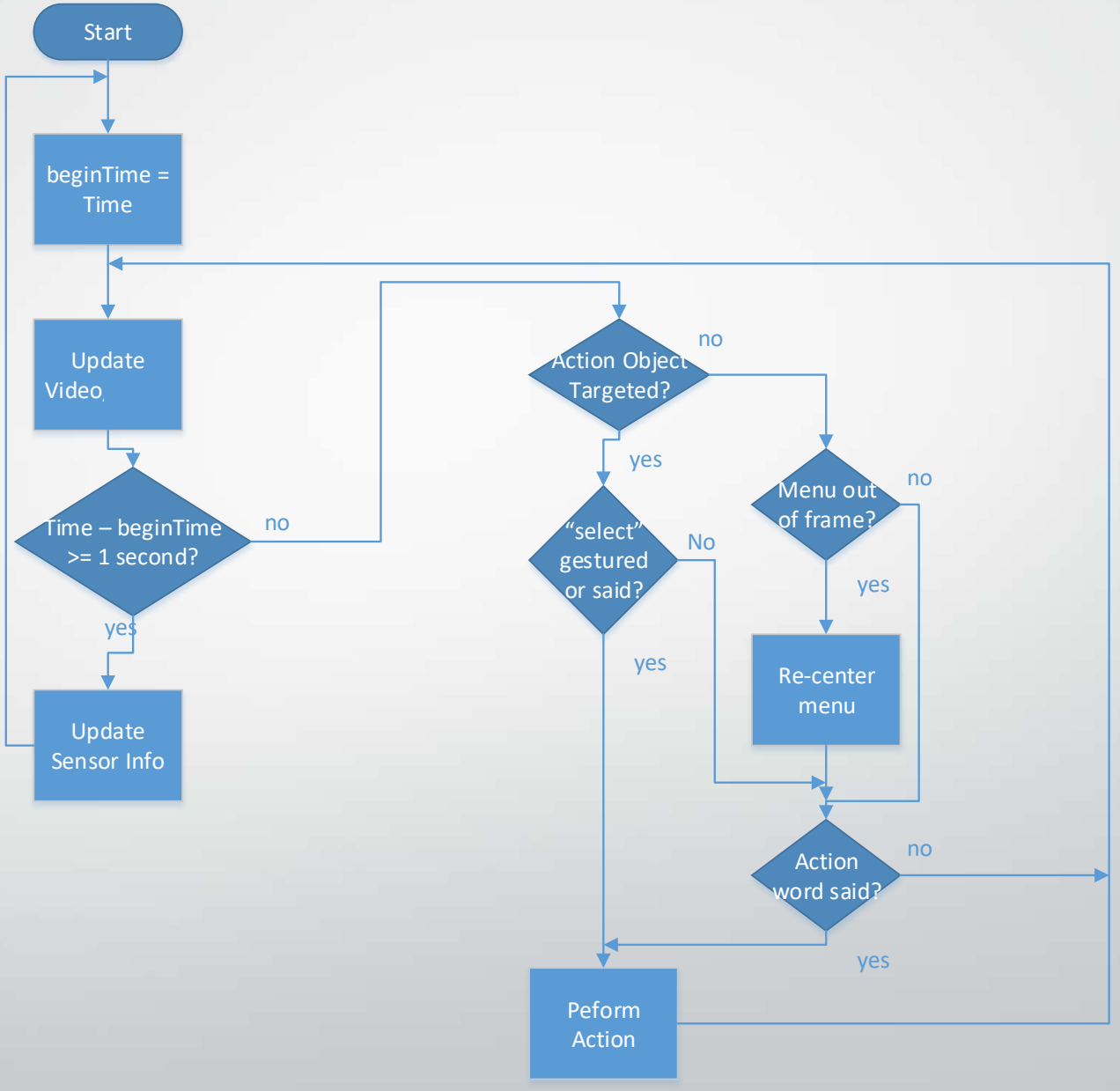




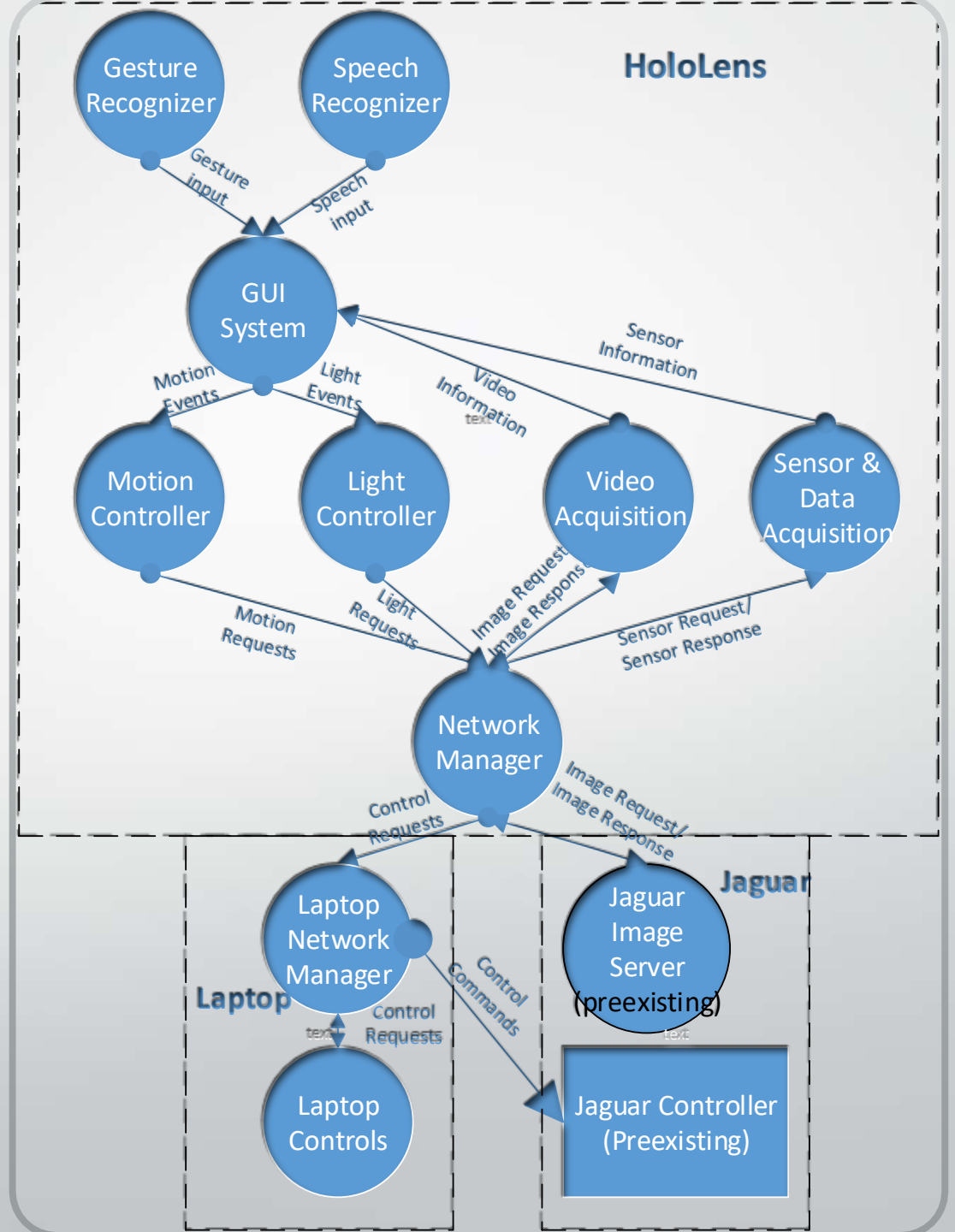
Software Design

- HoloLens application developed using Unity3D with C# scripts
  - Standard for HoloLens
- Laptop control program developed using C#
  - Optimized for network communication
  - Consistent with HoloLens
  - Jaguar SDK based on C# code

Software Functional Diagram



Overall System Data Flow



Implemented System Descriptions: Input Recognition

- Function:
  - Detects user interaction with objects
- Mechanism:
  - Gestures
    - Uses Unity VR library's gesture recognizer to identify gestures
    - Uses gaze direction to determine if user is selecting valid action object
      - If so, triggers event on corresponding object
  - Speech
    - Uses Unity's speech recognizer library
    - Created a dictionary of key phrases used to activate actions
    - Upon phrase recognition, calls event corresponding to action

Implemented System Descriptions: GUI System

- Function:
  - Ensures correct positioning of menu objects
  - Provide selection feedback to user
  - Format data output
  - Occlude user's vision as little as possible
- Mechanism:
  - Uses internal gyroscopes and accelerometers of HoloLens to determine position and orientation of device
    - Used to detect if too much of menu is out of viewing range or is too close or far to HoloLens
    - If so, menu re-centers at default distance
  - Uses color lerp to flash selected object to a different color to confirm selection
  - Accesses values from data acquisition and packages them to be displayed

Implemented System Descriptions: HoloLens Controllers

- Function:
  - Determines and encodes commands to send to Jaguar
- Mechanism:
  - Identifies object called
  - Based on object and current status encodes command to be sent
  - Triggers network manager to send command

Implemented System Descriptions: Video and Data Acquisition

- Function:
  - Manages retrieval and packaging of information from robot
- Mechanism:
  - Requests network manager to retrieve image information at a rate equal to the frame rate
  - Takes information and assigns it to the video object texture
  - Requests network manager to retrieve sensor information once per second
  - Stores response in displayable string

Implemented System Descriptions: HoloLens Network Manager

- Function:
  - Facilitates HoloLens-tablet and HoloLens-image server communications
- Mechanism:
  - Uses Windows.Networking streamsockets to communicate with tablet using TCP
    - Sends control commands to be executed
    - Sends requests for information
      - Listens to reply to obtain raw data from robot
  - Uses HTTP client to send GET requests to the Jaguar image server
    - Allows encoding of credentials since server is protected
    - Stores response in a byte array to be packaged as a JPEG

Implemented System Descriptions: Tablet Network Manager

- Function:
  - Receives commands from HoloLens to send to Jaguar
- Mechanism:
  - Uses a TCP listener to detect messages from HoloLens
  - Packages incoming message to be processed by the tablet control program
  - If receiving a GET request, responds with appropriate data

Implemented System Descriptions: Tablet Controller

- Function:
  - Allows final transmission of signals to Jaguar
- Mechanism:
  - Decodes received message to determine desired action
  - Uses Jaguar SDK to transmit control or access command to Jaguar

Results: GUI Capabilities

- Allows selection with gestures, speech and clicker
- Graphical feedback for user input and motion conditions
- Follows user's head movements

Results: Sensing Capabilities

- Currently get 1 Hz updates of:
  - Battery temperature (˚C)
  - Battery voltage (V)
  - Right and left motor speeds (pulses/second)

Video Capabilities

- 800x600 resolution images
- 10 frames per second
- ~1 second latency
- Small screen mode
  - Can adjust size and position using speech commands
- Full screen mode
  - Can enter and exit using speech
  - Takes up entire view space with sensor information overlaid

Results: Control Capabilities

- <1 second end-to-end response time to user input
- Ability to:
  - Accelerate forward and backward
  - Turn clockwise and counterclockwise at constant velocity until terminated
  - Turn headlights on and off

Results: Safety Features

- Able to initiate stop at any time
- Tablet control program terminates robot motion after 1 second of HoloLens silence
- Jaguar shuts down after 5 seconds of tablet silence (intrinsic to Jaguar)

Cost Analysis

- HoloLens Development Edition: $3,000 (already owned)
- Jaguar 4x4 Wheel Robot with Manipulator Arm: $18,750 (already owned)
- Total Cost: $21,750

Limitations/Future Work

- 300 meter range due to Jaguar router
  - Plan to make securely accessible through WiFi
- Need to use tablet as bridge
  - Use Jaguar protocol to directly connect from HoloLens
- No arm
  - Expand design to provide arm control
- Inconsistent control
  - Use feedback and modelling in control program

Conclusions

- Have control and monitoring with one device
- Multiple methods of hands free control
- Greatly reduces occlusion, distortion and encumbrance compared to other designs
- Lots of room for expansion!

Acknowledgements

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  - Victor Bershinsky (course instructor)
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Questions?