

COOPERATIVE CONTROL OF HETEROGENEOUS MOBILE ROBOTS NETWORK

Gregory Bock, Brittany Dhall, Ryan Hendrickson, & Jared Lamkin **Project Advisors:** Dr. Jing Wang & Dr. In Soo Ahn Department of Electrical and Computer Engineering November 24th, 2015

Outline

I. Introduction

- II. E-puck Progress Brittany
- III. Kilobot Progress Jared
- IV. Qbot Progress Ryan & Greg
- V. Summary & Conclusions

I. Introduction

Problem Description

 Design cooperative control algorithms for heterogeneous groups of robots

 Implement algorithms on different robot platforms

Objectives

- Design and Experimental Validation of Cooperative Control Algorithms
 - Sensing/communication between robots
 - Implementation of local flocking control algorithms
 - Implementation of local formation control algorithms

Solution

Cooperative control algorithm design

- Linear model
- Non-linear model
- Deployment and validation through experimental testing
 - Modular design
 - System integration

Algorithm Test Platforms

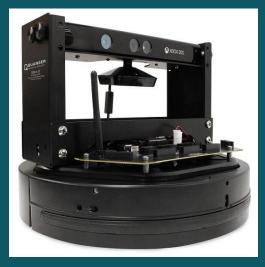
Kilobot



E-Puck



Qbot



Division of Labor Overview

	Kilobots	Jared					
Individual Behavior	Qbots	Ryan/Greg					
	E-pucks						
	Kilobot - Kilobot	Jared					
Individual Communication	Qbot - Qbot	Ryan/Greg					
	E-puck - E-puck	Brittany					
	Kilobot - E-puck	Jared/Brittany					
Integrated Communication	Kilobot - Qbot	Jared/Ryan/Greg					
	E-puck - Qbot	Brittany/Ryan/Greg					
Algorithm Design	Linearization Based Model	Jared/Brittany/Ryan/Greg					
Integrated Behavior	Formation Control Behavior	Jared/Brittany/Ryan/Greg					
	Flocking Behavior	Jared/Brittany/Ryan/Greg					
Tosting	Software Implementation	Jared/Brittany/Ryan/Greg					
Testing	Hardware Implementation	Jared/Brittany/Ryan/Greg					

II. E-puck Progress - Brittany

Gantt Chart – Work Accomplished

Task Name	Group Member	Finish by	0	Nov-15					
	Responsible for Task	Date	13	20	27	3	10	17	24
		October							
Research E-puck Sensors	Brittany	26, 2015							
Research E-puck Communication		November							
Protocol	Brittany	16, 2015							
		December							
Research/Test E-puck - E-puck	Brittany	14, 2015							
		December							
Test Kilobot - E-puck	Jared/Brittany	14, 2015							
	Brittany/Ryan/	December	_						
Test E-puck - Qbot	Greg	14, 2015							

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Work Accomplished

- Sensor research
- Communication protocol
- Software & hardware implementation
- Object detection/following



Sensor Research

Infrared receiver

 Will be used to communicate with other robot platforms

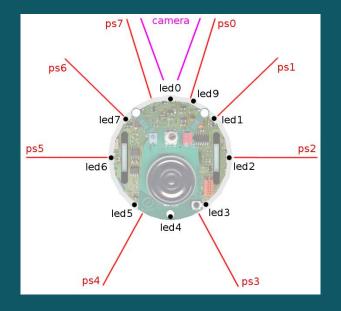
Distance measurement sensors

- Used to detect and follow an object
- Used for collision avoidance



Infrared proximity sensors

8 infrared proximity sensors Composed of two parts IR emitter & photo-sensor e_get_prox(int sensor_number)



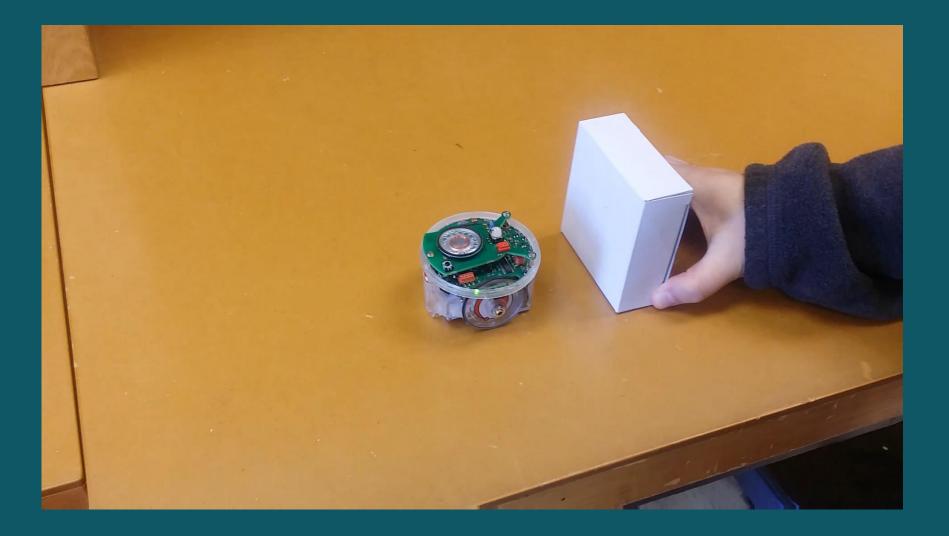
E-puck Monitor

🖲 e-puck monitor		
Port COM7	Test all actuators	
Pause	✓ sensor refresh	
	Rotate • <td></td>	
	Get image Send para	IR check 0 IR address 0 IR data 0
Click to move	Accelerometer orientation	0
Stop		Micro Amplitude

Object Detection



Object Following



Problems Encountered

- Loss of battery life
- Infrared sensor communication
- Two disabled E-pucks
 - Using an ICD₃ programmer to enable the E-pucks



http://www.microchip.com/Developmenttools/ProductDetails.aspx?PartNO=DV164 035&utm_source=&utm_medium=MicroSolutions&utm_term=&utm_content=DevT 00ls&utm_campaign=MPLAB+ICD+3+In-Circuit+Debugger

Future Work

- Continue to understand infrared communication
- E-puck to E-puck communication
- E-puck to Kilobot communication
- E-puck to Q-bot communication
- Enable 2 disabled E-pucks

Gantt Chart - Future Work

	Group Member	er Finish by Nov-1				D	ec-	15			Jan-16		6	Feb		6
Task Name	Responsible for Task	Date	17	24	1	8	15	22	29	5	12	19	26	2	9	16
Research/Test E-puck - E-puck	Brittany	December 14, 2015														
Test Kilobot - E-puck	Jared/Brittany	December 14, 2015														
Test E-puck - Qbot	Brittany/Ryan/Greg	December 14, 2015														
Design Linear Based Model	All	December 14, 2015														
Localization	All	January 25, 2016														
Point Convergence	All	January 25, 2016														
Leader Follower	All	January 25, 2016														
Neighbor Repulsion	All	February 1, 2016														
Endpoint Attraction	All	February 1, 2016														
Heading	All	February 1, 2016														

In progress

III. Kilobot Progress - Jared

Gantt Chart – Work Accomplished

	Group Member			ct-1	15		5		
Task Name	Responsible for Task	Finish by Date	13	20	27	3	10	17	24
Research/Test Kilobot									
- Kilobot	Jared	October 19, 2015							
		December 14,							
Test Kilobot - E-puck	Jared/Brittany	2015							
		November 16,							
Test Kilobot - Qbot	Jared/Ryan/Greg	eg 2015							
Design Linear Based		December 14,							
Model	All	2015							
Localization	All	January 25, 2016							
Point Convergence	All	January 25, 2016							
Leader Follower	All	January 25, 2016							
Neighbor Repulsion	All	February 1, 2016							
Endpoint Attraction	All	February 1, 2016							
Heading	All	February 1, 2016							

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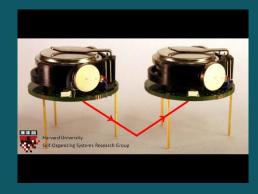
Kilobot Communication

• 50% complete

- Successfully sent messages to Kilobots
- Currently implementing a receiver circuit

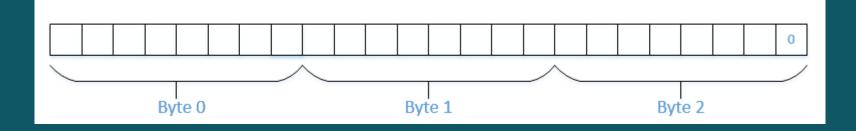
How Kilobots Communicate

- Use infrared light
- Reflects light off the floor
- Measures light intensity to calculate distance
- Maximum rated range is 7 cm
- Messages are sent every 200 milliseconds



Preparing Messages to send

- A message is composed of 23 bits (2 full characters, and an even character)
- A check sum is generated by taking the sum of the bits and 128
- All four bytes are operated on
- Each byte is then shifted left and incremented by 1

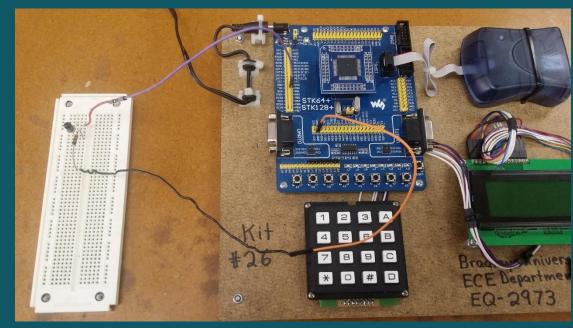


Sending messages

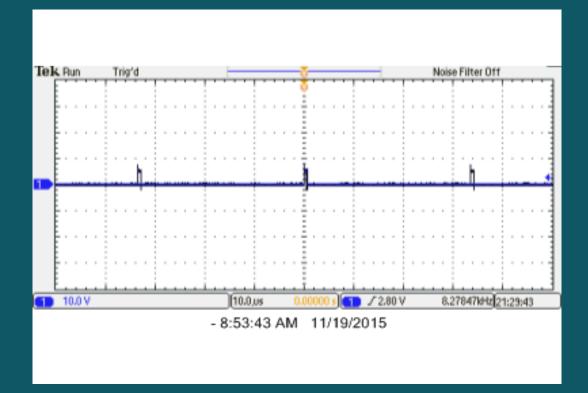
- Signal goes high briefly (0.75 microseconds)
- Signal is then set low for a duration (92.25 microseconds)
- Each bit is sent: high for 1, low for 0
- Signal is set low between each bit (13.875 microseconds per bit)
- 537 microseconds for entire message to be sent

Circuit

Used an Atmega128 board from the lab
PBo in series with a 330 ohm resistor and an IR LED



Oscilloscope capture



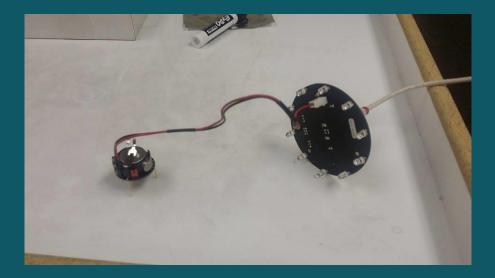
Initial Testing

 A Kilobot was programmed to turn its LED green if message was received

- The Kilobot turns it LED red if message is not received after a set amount of time
- The IR LED light was reflected off the ground next to the Kilobot

Further Testing

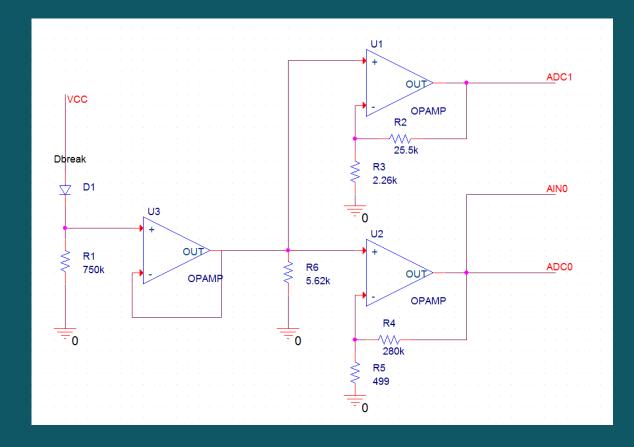
- Kilobot was connected to serial cable and programmed to print message values to hyper terminal
- Kilobot was placed at measured distances and compared to printed distance



Receiving messages

- Uses analog-to-digital conversion (ADC)
- Interrupt is triggered when IR receiver gets a pulse
- Uses the ADC gain to calculate distance

Receiver Circuit Diagram



Receiving circuit

- IR receiver is wired in series to the voltage source and resistors
- An op-amp is configured to a buffer and the + terminal is connected between the resistors and IR receiver
- The output of the buffer is then connected to two non-inverting configured op-amps
- The outputs of the two op-amps are then connected to the ADC channels on the microcontroller

Color Consensus

- Kilobots are initialized with a random number
- Each number corresponds to a color
- Kilobots then begin transmitting value
- Kilobots receive messages and keep track of how many neighbors are what color
- Kilobots then change their color to most prevalent color

Color Consensus Video



Localization

- Use a distributed Trilateration method
- Requires a minimum of 3 localized and noncollinear agents
- Agents initially assume a position of (0,0)
- Distances to localized Kilobots is known

Gantt Chart – Future Work

Task Name	Group Member Responsible for	Finish by Date		Finish by Date		·								Jai	n-10	Feb-16		
	Task		17	24	1	8	15	22	29	5	12	19	26	2	9	16		
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Test Kilobot - E-puck	Jared/Brittany	2015																
		November 16,																
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Leader Follower	All	January 25, 2016																
Neighbor Repulsion	All	February 1, 2016																
Endpoint Attraction	All	February 1, 2016																
Heading	All	February 1, 2016																

III. Qbot2 Progress – Ryan & Greg

Qbot2 Progress - Ryan

Gantt Chart – Work Accomplished

	Group Member		0	ct-1	5		No	v-1	5
Task Name	Responsible for Task	Finish by Date	13	20	27	3	10	17	24
Research Q-bot									
Communication Protocol	Ryan/Greg	October 19, 2015							
Research/Test Qbot - Qbot	Ryan/Greg	November 2, 2015							
Test Kilobot - Qbot	Jared/Ryan/Greg	November 16, 2015							
Test E-puck - Qbot	Brittany/Ryan/Greg	December 14, 2015							
Design Linear Based Model	All	December 14, 2015							
Localization	All	January 25, 2016							
Point Convergence	All	January 25, 2016							
Leader Follower	All	January 25, 2016							

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Qbot2 Progress

Qbot-to-Qbot Communication

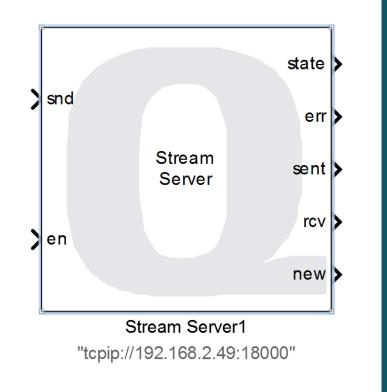
Depth Sensing

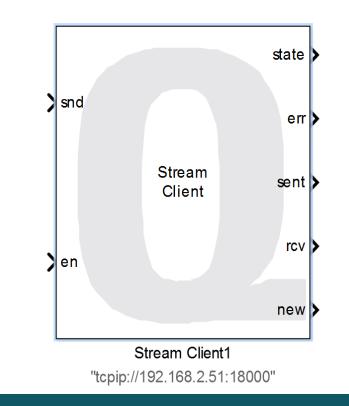
On-Board PWM

Qbot-to-Qbot Communication

Stream Server and Stream Client blocks
Only one connection to block at a time
Stays connected if MATLAB closes

Stream Server and Stream Client





Stream Server and Stream Client

n	Source Block Parameters: Stream Server1		Source Block Parameters: Stream Client1
6	Stream Server Listens for and accepts a connection from a remote host and sends and/or receives data from that host.		Stream Client Connects to a remote host and sends and/or receives data from that host.
	Main Advanced Signal Data Types	ll	Main Advanced Signal Data Types
ł	Source of URI: Specify via dialog (do not evaluate)		Source of URI: Specify via dialog (do not evaluate)
	URI upon which to listen: tcpip://192.168.2.49:18000		URI of host to which to connect: tcoip://192.168.2.51:18000
e: ie	Apply URI to all configurations (including normal simulation)		Apply URI to all configurations (including normal simulation)
1	Send buffer size in bytes:		Send buffer size in bytes:
	1460		1460
	Receive buffer size in bytes:		Receive buffer size in bytes:
1	1460		1460
ł	Byte ordering: little endian (Intel - LSB first)		Byte ordering: little endian (Intel - LSB first)
n	Optimize for: Minimum latency		Optimize for: Minimum latency
56	Send options: Send all data		Send options: Send all data
	Receive options: Receive all data		Receive options: Receive all data
	Default output value:		Default output value:
	[0 0 0 0 0]		[0 0 0 0 0]
	Sample time (seconds):		Sample time (seconds):
	qc_get_step_size		qc_get_step_size
	Active during normal simulation		Active during normal simulation
d	OK Cancel Help Apply		OK Cancel Help Apply

Infrared (IR) Kinect Depth Sensor
No more pixel count for distance
Walls and other obstacles now can be avoided



On-Board PWM

Qbot clock of 1 gigahertz (GHz)
Default sampling frequency of 100 hertz
Simpler to use microcontroller

Sampling Time

🚳 Configuration Parameters: Omeg	a49/Linux DuoVero Configuration (Active)	22
Select: Solver Data Import/Export Optimization Diagnostics Hardware Implementation Model Referencing	Type: Tisked Step	Solver: ode4 (Runge-Kutta)
 Simulation Target Code Generation 	Fixed-step size (fundamental sample time): Tasking and sample time options Periodic sample time constraint: Tasking mode for periodic sample times: Image: Automatically handle rate transition for data transfer Image: Higher priority value indicates higher task priority	0.01 Unconstrained Auto

Sampling Time

Source Block	Parameters:	Kinect Initialize	2	x
– Kinect Initialize–				
Initializes a Kineo	ct sensor.			
Navigation				
Goto Kinect b	olocks using th	his Kinect senso	r	
Kinect name:				
Kinect-1				
Kinect type:	Kinect for Xt	oox 360		•
Kinect identifier	r:			
0				
Sample time (se	econds):			
qc_get_step_s	size * 10			
Active during Active during	ng normal sim	ulation		
(ОК	Cancel	Help	pply

Gantt Chart – Future Work

Task Name	Group Member	Finial by Data	Nov	v- 15		D	ec-i	15			Jai	1-1(5	Fe	b-16	٦
	Responsible for Task	Finish by Date	17	24	1	8	15	22	29	5	12	19	26	2	91	6
Test Kilobot - Qbot	Jared/Ryan/Greg	November 16, 2015														
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Heading	All	February 1, 2016														

Qbot2 Progress - Greg

Gantt Chart – Work Accomplished

Task Name	Group Member	Finish by Doto	(Oct-1	.5		No	v-1:	5
	Responsible for Task	Finish by Date	13	20	27	3	10	17	24
Design Linear Based Model	All	December 14, 2015							
Formation Control Behavior									
Localization	All	January 25, 2016							
Point Convergence	All	January 25, 2016							
Leader Follower	All	January 25, 2016							

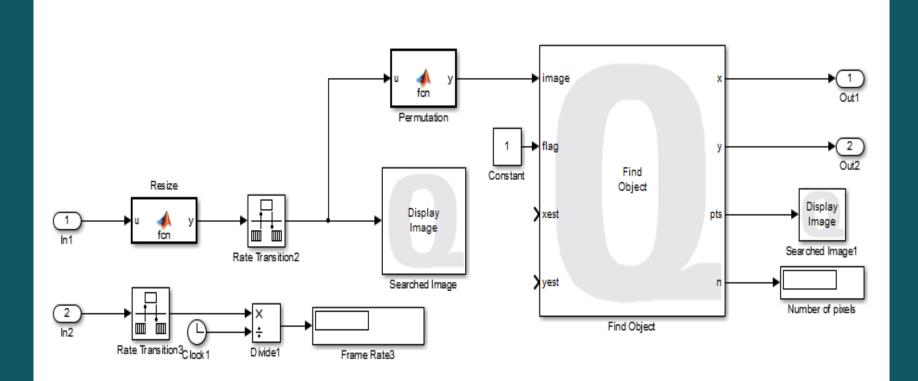
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Localization

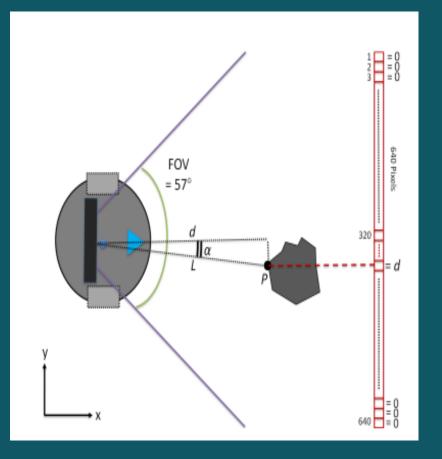
Three main steps

- Identify object
- Determine depth and angle of object
- Communicate calculated x and y values

Identify Object



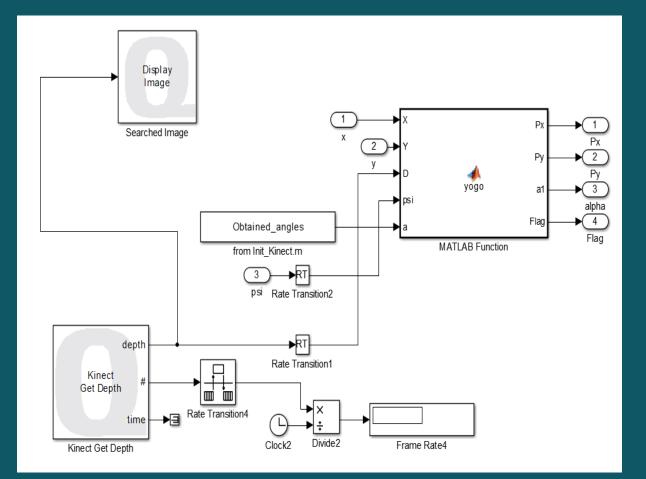
Determine Depth & Angle



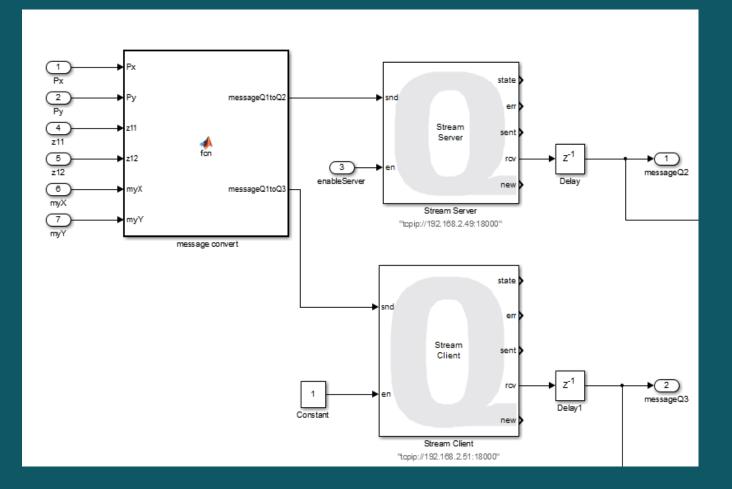
Distance determined by depth sensor is the value d.

• $y = d \tan \alpha$

Determine Depth & Angle



Communicate Calculated Values



- Qbots communicate localized coordinates
- Velocities are determined from the difference of communicating Qbots' coordinates

Equations

- $V_{11} = K(Z_{21} Z_{11})$
- $V_{12} = K(Z_{22} Z_{12})$
- $V_{21} = K(Z_{31} Z_{21})$
- $V_{22} = K(Z_{32} Z_{22})$
- $V_{31} = K(Z_{11} Z_{31})$
- $V_{33} = K(Z_{12} Z_{32})$

Equations

- $Z_{n1} = x_n + d\cos\theta$
- $Z_{n2} = y_n + d\sin\theta$

•
$$Z'_{n1} = V \cos \theta - d \sin(\theta) \omega$$

•
$$Z'_{n2} = V \sin \theta + d \cos(\theta) \omega$$

•
$$\begin{bmatrix} V \\ \omega \end{bmatrix} = \begin{bmatrix} \cos \theta & -d \sin \theta \\ \sin \theta & d \cos \theta \end{bmatrix}^{-1} \begin{bmatrix} V_{n1} \\ V_{n2} \end{bmatrix}$$



Gantt Chart – Future Work

Task Name	Group Member	Einich by Doto	Nov	v-15		D	ec-1	15			Jar	1-10		b-1(6	
	Responsible for Task	Finish by Date	17	24	1	8	15	22	29	5	12	19	26	2	-9	16
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Leader Follower	All	January 25, 2016														
Flocking Behavior																
Neighbor Repulsion	All	February 1, 2016														
Endpoint Attraction	All	February 1, 2016														
Heading	All	February 1, 2016														

VIII. Summary & Conclusions

Summary & Conclusions

- Design cooperative control algorithms for heterogeneous groups of robots
- Implement algorithms on different robot platforms
- Prevent collisions and implement network security
- Behind Schedule

Future Plan of Action

- Communication between platforms
- Algorithm design
- Integrated behavior



COOPERATIVE CONTROL OF HETEROGENEOUS MOBILE ROBOTS NETWORK

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Abbreviated Gantt Chart

Task Name	Torract Datas		S	ep	-15)		Oc	:t-1	5		No	v-1	5		D)ec	-15	5		Ja	n-1	6		Fe	b- 1	6		Μ	ar-	·16	
	Target Dates	1	8	15	22	29	6	13	20	27	3	10	17	24	1	8	15	22	29	5	12	19	26	52	9	16	23	1	8	15	22	29
Individual Behavior	November 10, 2015																															
Individual Communication	December 14, 2015																															
Integrated Communication	December 14, 2015																															
Algorithm Design	December 14, 2015																															
Integrated Behavior	February 1, 2016																															
Testing	March 7, 2016																															

Complete Gantt Chart

Task Name	Group Member Responsible for Task	Finish by Date/Due Date		Se	o-15_		0	Oct-1	.5	N	lov-1	5	D	ec-1	5	J	lan-1	6	Fe	b-16	I	Mar	-16		Ap	r-16
			18	3 15	22	29	6 13	3 20) 27	31	0 17	24	181	52	2 29	51	2 19	26	29	16 23	18	15	22	29 5	12	19 26
Individual Behavior																										
Research Kilobot Sensors	Jared	September 28, 2015																								
Research Kilobot Communication Protocol	Jared	October 12, 2015																								
Research Q-bot Image Processing	Ryan/Greg	October 5, 2015																								
Research Q-bot Sensors	Ryan/Greg	September 28, 2015																								
Reseach Q-bot Communication Protocol	Ryan/Greg	October 19, 2015																								
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Research E-puck Communication Protocol	Brittany																									
Individual Communication																										
Research/Test Kilobot - Kilobot	Jared	October 19, 2015																								
Research/Test E-puck - E-puck	Brittany	December 14, 2015																								
Research/Test Qbot - Qbot	Ryan/Greg	November 2, 2015																								
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Test Kilobot - E-puck	Jared/Brittany	December 14, 2015																								
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Neighbor Repulsion	All	February 1, 2016																								
Enpoint Attraction	All	February 1, 2016																								
Heading	All	February 1, 2016																								
Testing																										
Software Implementation	All	March 7, 2016																								
Hardware Implementation	All	March 7, 2016																								

Deliverable Gantt Chart

Task Name	Group Member Responsible for Task	Finish by Date/Due Date		Se	p-15	;		Oc	t-15	;	N	lov-1	15		Dec	-15		Ja	n-1(6	Fel	o-16		Ma	r-16		A	pr-1	6
			1	8 15	5 22	29	96	13	20	27	3 1	0 17	24	18	15	22	29 :	5 12	19	26	29	16 2	31	8 15	22	29	5 12	2 19	26
Deliverables																													
Project Proposal - Oral Presentation	All	October 1, 2015																											
Project Proposal - Document	All	October 15, 2015																											
Webpage Release	All	October 28, 2015																											
Fall Progress Presentation	All	November 19, 2015																											
Fall Performance Evaluation	All	November 19, 2015																											
Fall Performance Review	All	Decemeber 3, 2015																											
Spring Progress Presentation	All	Feburary 18, 2016																											
Student Expo Abstract	All	March 18, 2016																											
Progject Demostration	All	March 24, 2016																											
Final Presentation	All	April 7, 2016																											
Student Expo Poster Printing Deadline	All	April 11, 2016																											
Student Expo Poster Setup	All	April 12, 2016																											
Sudent Expo	All	April 14, 2016																											
Final Report (Draft)	All	April 14, 2016																											
Final Report	All	April 28, 2016																											
Final Web Page	All	April 28, 2016																											
Advisory Board Poster Printing Deadline	All	April 28, 2016																											
Advisory Board Poster Presentation	All	April 29, 2016																											

Design Constraints

- Must overcome limited communication among networked robots
- Must overcome limited sensing capability of robots
- Must overcome system uncertainties

Objectives

Mobile robot network should be applicable to different robot platforms

- Mobile robot network should be robust
- Mobile robot network should be autonomous

Solution

Cooperative control algorithm design

- Linear model
- Non-linear model
- Deployment and validation through experimental testing
 - Modular design
 - System integration

Robot Model

Linear Model

- $\dot{x} = U_x$
- $\dot{y} = U_y$
- Non-linear Model
 - $\dot{x} = v cos(\theta)$
 - $\dot{y} = vsin(\theta)$
 - $\dot{\theta} = \omega$

Solution Testing

Software Implementation

- Simulation
- Algorithm validation
- Algorithm implementation on platforms
- Hardware Implementation
 - Robot calibration
 - Multiple sensor fusion
- System Integration
 - Software
 - Hardware

Criteria to Determine a Successful Project

- Algorithm can be deployed on multiple robots
- Autonomous robots
- Communication amongst multiple robots

Project Funding

- Air Force Research Lab
- Air Force Proposal "Multiagent task coordination using a distributed optimization approach"
- Grant Agreement Number FA8780-13-1-0109



Expenses

Robotic platforms (software included)
Auxiliary components

Project Platform Costs

Platform	Quantity	Total Price
Qbot2	3	\$9,999.00
Kilobot Kit	20	\$4,583.00
Epucks	3	\$5,093.00

Programming Software Costs

Software	Quantity	Total Price
Kilobot Controller IDE	1	\$0.00
E-puck Programming Software	1	\$0.00
MATLAB Courseware	1	\$0.00

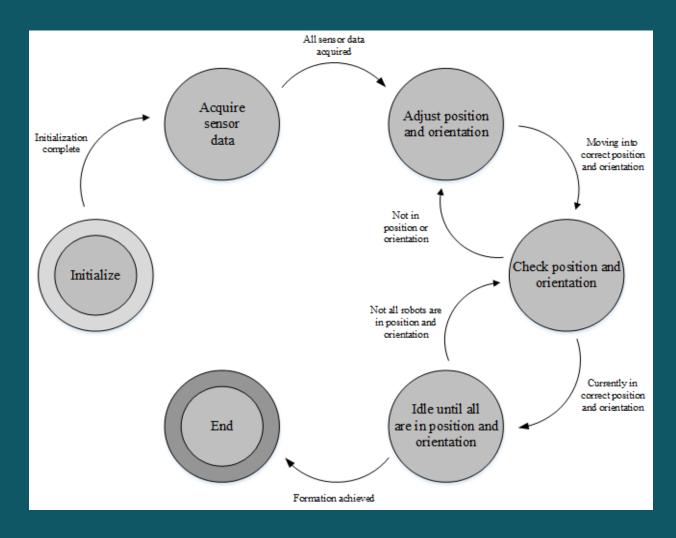
Gantt Chart

Task Name	Group Member Responsible for Task	Finish by Date		Se	p-15			Oct	t-15		1	Nov	-15			Dec	-15		Jan-16 Feb-1				b-16		M	lar-1	16		Ар	or-16	6	
			1	8 15	22	29	9 6	13	20	27	3	10	17	24	18	15	22	29	29 5 12 19 26 2 9 16 23						23 1	8	15 2	29 5	12	19	26	
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Research/Test Qbot - Qbot	Ryan/Greg	November 2, 2015																														
Integrated Communication																																
Test Kilobot - E-puck	Jared/Brittany	December 14, 2015																														
Test Kilobot - Qbot	Jared/Ryan/Greg	November 16, 2015																														
Test E-puck - Qbot	Brittany/Ryan/Greg	December 14, 2015																														
Algorithm Design																																
Design Linear Based Model	All	December 14, 2015																														
Integrated Behavior																																
Formation Control Behavior																																
Localization	All	January 25, 2016																														
Point Convergence	All	January 25, 2016																														
Leader Follower	All	January 25, 2016																														
Flocking Behavior																																
Neighbor Repulsion	All	February 1, 2016																														
Endpoint Attraction	All	February 1, 2016																														
Heading	All	February 1, 2016																														
Testing																																
Software Implementation	All	March 7, 2016																														
Hardware Implementation	All	March 7, 2016													Π								Π									

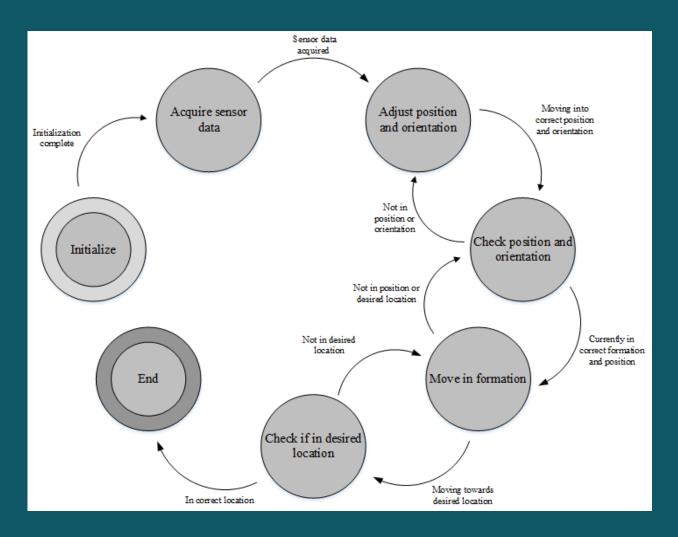
Gantt Chart – Deliverables

	Finish by Date/Due	S	lep	-15	5	0	oct-	-15	Т	No)v-]	15]	Dec	:-1	5	J	an	-16	16 Feb-16					lar	-10	5	Apr-16				
Task Name	Date																											512				
Deliverables																																
Project Proposal - Oral																																
Presentation	October 1, 2015																															
Project Proposal - Document	October 15, 2015																															
Webpage Release	October 28, 2015																															
Fall Progress Presentation	November 19, 2015																															
Fall Performance Evaluation	November 19, 2015																															
Fall Performance Review	December 3, 2015																															
Spring Progress Presentation	February 18, 2016																															
Student Expo Abstract	March 18, 2016																															
Project Demonstration	March 24, 2016																															
Final Presentation	April 7, 2016																															
Student Expo Poster Printing																																
Deadline	April 11, 2016																															
Student Expo Poster Setup	April 12, 2016																															
Student Expo	April 14, 2016																															
Final Report (Draft)	April 14, 2016																															
Final Report	April 28, 2016																															
Final Web Page	April 28, 2016																															
Advisory Board Poster Printing																																
Deadline	April 28, 2016																															
Advisory Board Poster																																
Presentation	April 29, 2016																															

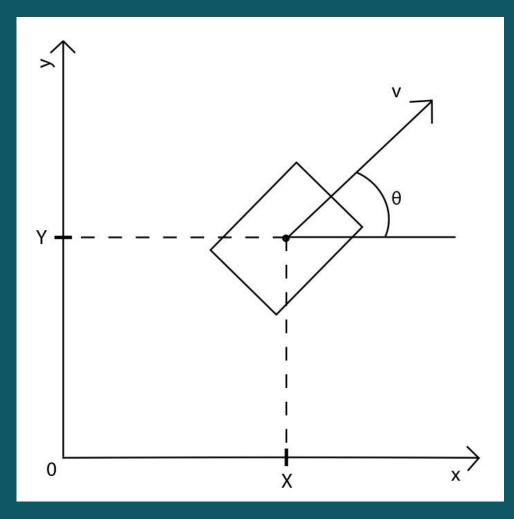
State Diagram: Formation Control Behavior



State Diagram: Flocking Formation

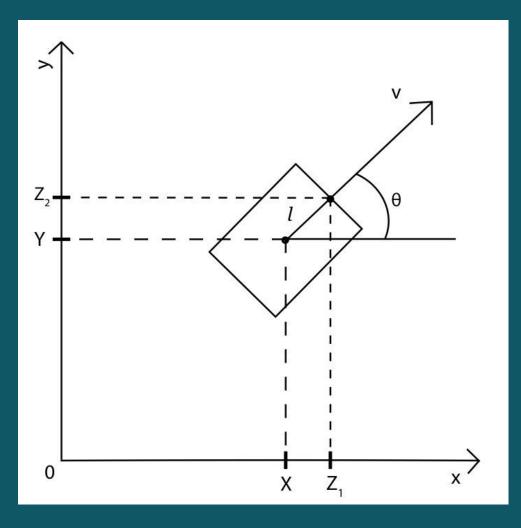


Non-linear Model



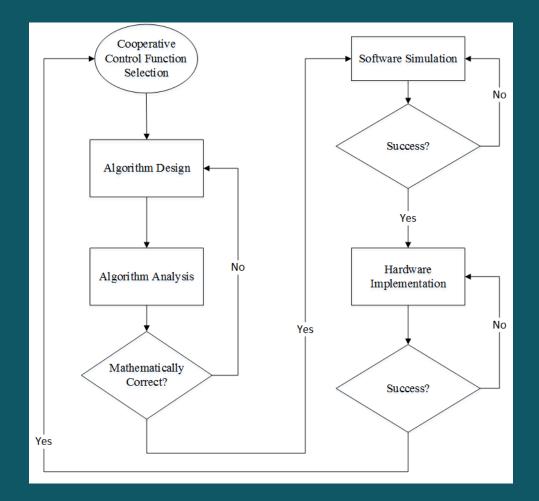
Quanser Inc. "QBOT 2 Workbook" Markham, Ontario

Linear Model



Quanser Inc. "QBOT 2 Workbook" Markham, Ontario

Solution Testing



E-puck Object Following Code

```
/** Motor speed controlled depending on front proximity sensor values **/
#include "p30f6014A.h"
#include "e epuck ports.h"
#include "e init port.h"
#include "e ad conv.h"
#include "e prox.h"
#include "e_motors.h"
#define DELAY 50000
int main() {
   long timer = 0;
   //system initialization
   e init port();
                           // configure port pins
   e_init_ad_scan(ALL_ADC);
                           // configure Analog-to-Digital Converter Module
   while (1) {
      if (e get prox(0)> 500) {
                                 //escape
          e_set_speed_left(0);
          e set speed right(0);
      } else if (e get prox(0)>100) { //follow
          e set speed left(400);
          e set speed right(400);
      } else {
                                 //stop
          e set_speed_left(0);
          e_set_speed_right(0);
      //wait a little to let the robot move
      for(timer = 0; timer < DELAY; timer++);</pre>
```

Kilobot message operations

data_out[i]=(data_to_send[i] & (1<<0))*128 + (data_to_send[i] & (1<<1))*32 + (data_to_send[i] & (1<<2))*8 + (data_to_send[i] & (1<<3))*2+ (data_to_send[i] & (1<<4))/2+ (data_to_send[i] & (1<<5))/8 + (data_to_send[i] & (1<<6))/32 + (data_to_send[i] & (1<<7))/128;

data_out[i]=data_out[i]<<1; data_out[i]++;

LEDs and Buttons

 Found LED and Button addresses for reading and writing

- LEDs can be used for debugging
- Buttons can be used for synchronous startup

QBot Point Convergence Code

```
v11 = k1*(z21 - z11); % Calculate velocity in x direction
v12 = k2*(z22 - z12); % Calculate velocity in y direction
mat = [cos(myTheta) -d/2*sin(myTheta); sin(myTheta) d/2*cos(myTheta)];
myControl = inv(mat)*[v11;v12];
```

```
% Determine total velocity
V = myControl(1);
```

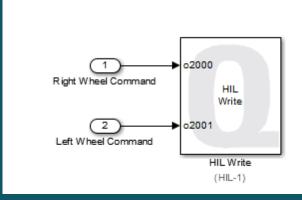
```
% Determine angular velocity
omega = myControl(2);
```

```
% Determine left and right wheel velocity
V1 = (2*V-d*omega)/2;
Vr = (2*V+d*omega)/2;
```

QBot Obtained Angle Equation

• $\alpha = (320 - column) * (57/640) * (\pi - 180)$

HIL Write Block



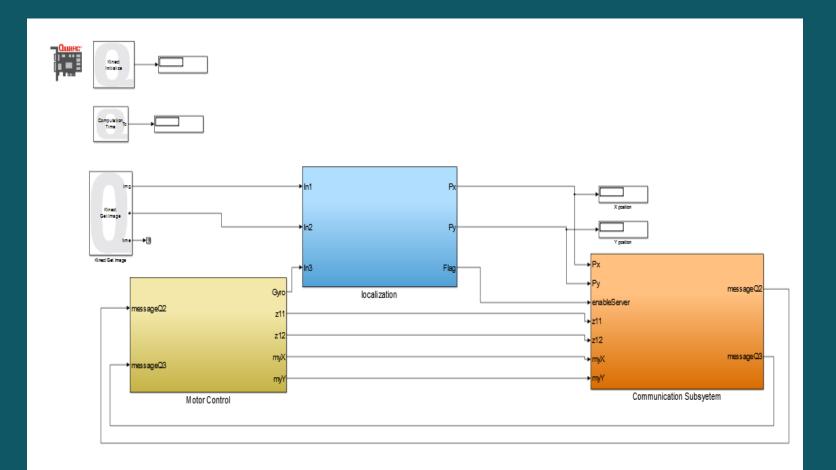
Source Block Parameters: HIL Write
HIL Write
Writes to a combination of output channels of a hardware-in-the-loop card.
Navigation
Go to HIL blocks using this board
Board name: HIL-1
Analog channels:
D
PWM channels:
0
Digital channels:
0
Other channels:
[2000:2001]
Sample time (seconds):
-1
Vector inputs
OK Cancel Help Apply

Find Object Parameters

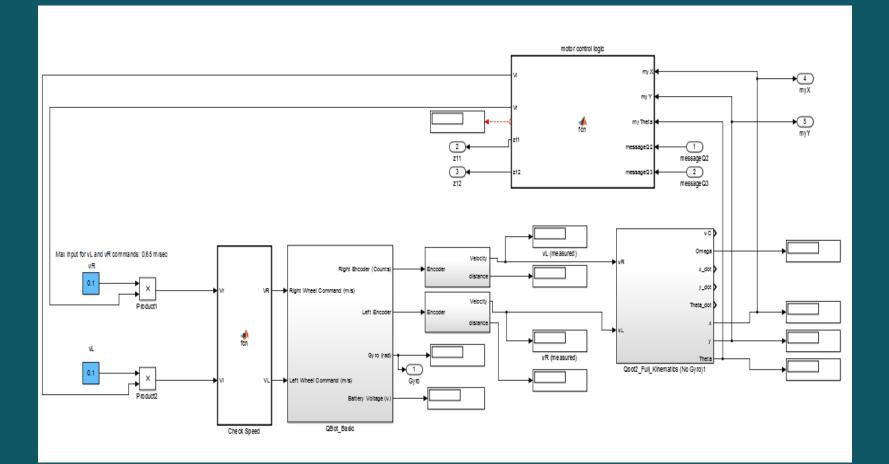
- Specify RGB values
- Value threshold
- Number of objects

Function Block Parameters: Find Object
Find Object (mask) (link)
Finds the center-of-mass coordinates (in pixels) of the object detected in the given image.
Parameters
Detection Mode: RGB
Pixel format: RGB8
Number of Objects (1-5):
1
Threshold:
30
Minimum object size (pixels):
16
R:
158
G:
201
в:
124
Sample Time (secs):
-1
OK Cancel Help Apply

Overall Simulink Model



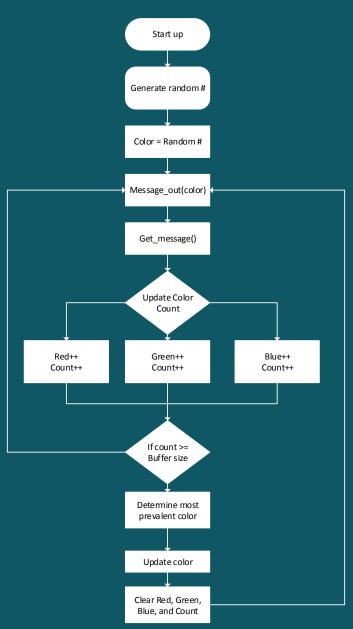
Motor Control



E-puck Tiny Bootloader

IIII Tiny Bootlo	oader - demo6.hex	
C:\Users\britt\E	Documents\Bradley\Senior Project\ledson.hex	<u>B</u> rowse
₩ rite Flash	Messages Terminal Options termOpt	
 CheckPIC	Interface to TinyBootLoader, v1.9.8 contact: claudiu.chiculita@ugal.ro http://www.etc.ugal.ro/cchiculita/software/picbootloader.htm	*
	Warning: piccodes.ini not found.	
Comm	Connected to \\.\COM7 at 115200 HEX: 4 days old, INHX32,dsPICcode, total=6488 bytes. Searching for PIC	
Search	Found:ds6014/6012 WRITE OK at 13:22, time:2.140 sec	
COM3 COM8 com7		
		*

Color Consensus Flowchart



Localization Equations

•
$$C_i = \sqrt{(x_0 - x_i)^2 + (y_0 - y_i)^2}$$

• $V_i = \langle \frac{x_0 - x_i}{C_i}, \frac{y_0 - y_i}{C_i} \rangle$
• $n_i = (x_i, y_i) - D_i * V_i$
• $(x_0, y_0) = (x_0, y_0) - \frac{(x_0 - n_{ix}, y_0 - n_{iy})}{4}$