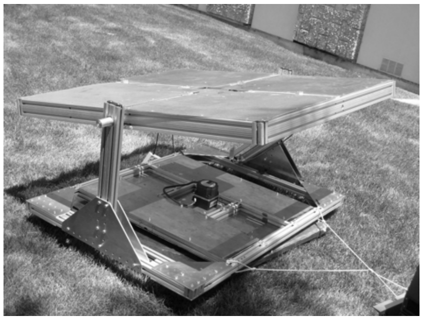
ISLANDS: A Self-Leveling Landing Platform for Autonomous Miniature UAVs



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Background

- Two most common forms of air vehicles

Planes first in 1899

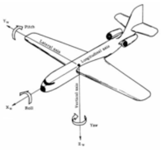
Then helicopters 1907

- 1916 first unmanned aerial vehicle (UAVs) developed as practice drones and were remote control operated
- First unmanned helicopter not developed until 1960 and used for bombing submarines (turned out to be failure and used as target practice drones)

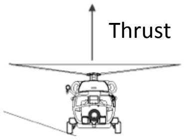
- Long delay between first unmanned plane and first unmanned helicopter because of the complexity in controlling helicopters

Background (cont.)

- Plane drawbacks
  - No hovering capability
    - Cannot maintain continuous surveillance without circling or periodic flybys
  - Cannot perform yaw rotation without *x,y* translation



  - Requires runway for take off/landing proportional to size of vehicle
- Helicopter capabilities
  - Hovering creates vehicles own lift through main rotor blade motions



  - No need for runway
  - Can perform yaw rotation without *x,y* translation
- Helicopter drawbacks
  - Shorter operating radius compared to similarly sized planes

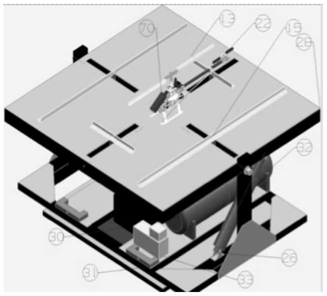
Motivation

- Increasing demand in class 1(<150kg) unmanned aerial systems- both fixed wing and rotorcraft
  - Due to potential cost saving and life saving
- For rotorcraft, smaller size means even shorter endurance but can operate in more areas
  - Can land atop rooftops
  - Fly between high-rise buildings
  - Companies already developing smaller helicopters for these applications

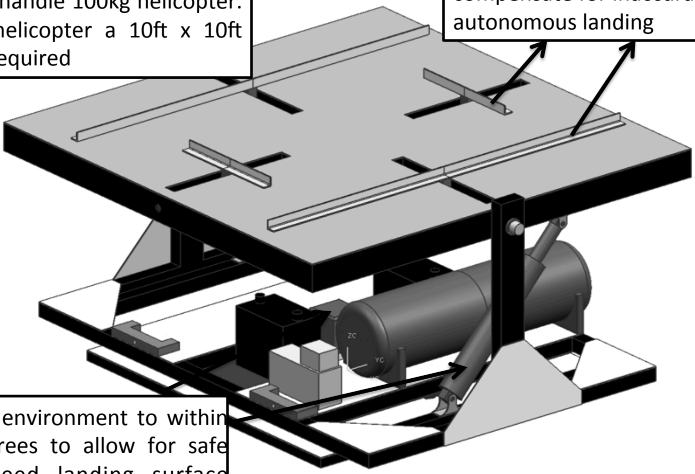
Examples of class 1 helicopters by Rotomotion

Problem Statement & Proposed Solution

- Develop a method to increase the mission endurance for small autonomous helicopters (Class 1, MTOW <=150kg)
- This is done by:
  - Developing an electromechanical device for safe landing and refueling or recharging in the form of ISLANDS
  - Algorithm to efficiently deploy ISLANDS



The ISLANDS system and Requirements



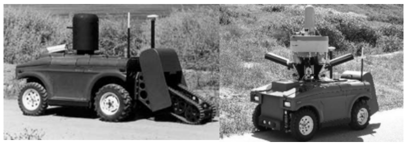
Current Design is 4ft x 4ft and over designed to handle 100kg helicopter. For 150kg helicopter a 10ft x 10ft platform is required

Centering mechanism to compensate for inaccuracy of autonomous landing

Leveling to environment to within +/- 25 degrees to allow for safe landing. Need landing surface parallel to rotor disc of helicopter to eliminate ground effect

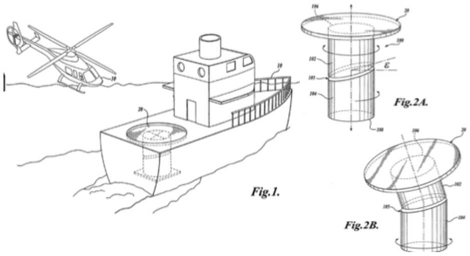
Related Work

- The Mobile Detection Assessment and Response System for the iSTAR VTOL system from the Space and Naval Warfare Systems command



- System is form factor dependent
- No refueling/recharging capabilities
- Does not self-level

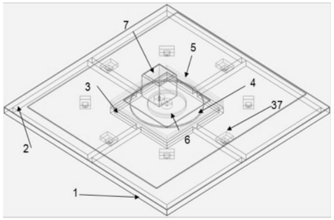
- A patent number 7,299,762 for a landing surface

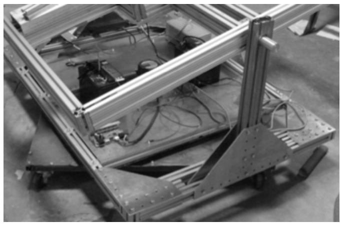


- No physical system
- Designed for ships
  - Not standalone unit
- Not designed for autonomous helicopters no centering mechanism
- High frequency/low amplitude

1^{st} DOF: Rotating Mechanism

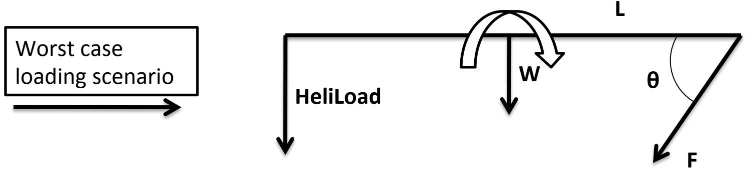
- One of the degrees of freedom needed to level ISLANDS to the environment
  - Responsible for rotating ISLANDS to align with the environment gradient
- Powered by a DC motor via a 1:1 gear train $\tau = i\alpha$
- To compute torque of motor
  - Where $i = \sum_{c=1}^{c=n} i_c$ is the sum of inertia components being rotated
  - Larger body broken into sub-bodies of simple geometries.
  - Parallel axis theorem used to align rotation with that of motor





2nd DOF: Leveling Mechanism

- Levels landing deck to the gradient that the rotation mechanism aligned with



  - HeliLoad – Weight of helicopter
  - W – weight of landing deck being rotated
  - L – distance between pivot and linear actuator attachment point
  - F – force needed to overcome moment M

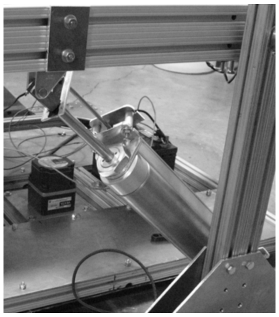
$$F = 2L(HeliLoad) + \frac{WL}{\sin(\theta)}$$

Force needed over range of +/- 25 degrees is 1200 N

Choosing Linear Actuator

- 3 types of Linear actuators available: Electric, Hydraulic, Pneumatic

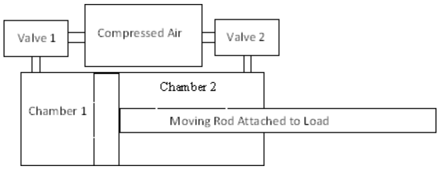
1. Electric
   - Easy to control
   - Weakest
   - Not back drivable (if system fails, stuck in that position)
2. Hydraulic
   - Easy to control due to incompressibility of working fluid (hydraulic oil)
   - Most powerful
   - Expensive, requires addition of pump, and manifold
     - If leak in system all working fluid lost system stop working
3. Pneumatic
   - Difficult to control
   - Powerful
   - Clean, working fluid is air
   - Cheap components
   - Back drivable



Pneumatics Background

- Basic governing equation for controlling pneumatic piston

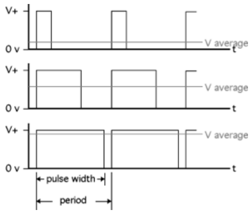
$$\left.\begin{aligned} M\frac{d^2x}{dt^2}+B\frac{dx}{dt}&=A(P_1-P_2)\\ P_1Ax&=m_1RT\\ P_2A(l-x)&=m_2RT \end{aligned}\right. \xrightarrow{\text{Derivative of Pressure}} \left.\begin{aligned} \frac{dP_1}{dt}&=\frac{1}{Ax}(-P_1A\frac{dx}{dt}+RT\dot{m_1})\\ \frac{dP_2}{dt}&=\frac{1}{A(l-x)}(-P_2A\frac{dx}{dt}+RT\dot{m_2}) \end{aligned}\right.$$



- Problems with this model
  - **Coefficient of friction varies and non linear**
  - Air is compressible hence ideal gas law relationship does not hold, assumed incompressible in some models
  - In this work went straight to implementation

Controlling Valves

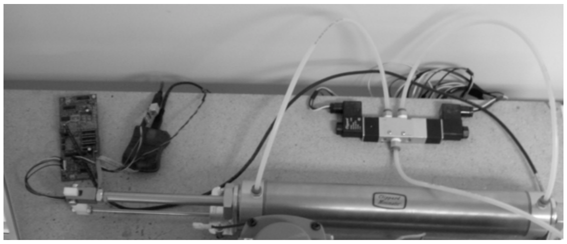
- Valves control flow of air into the chambers and hence the position of piston
- Two types of valves available:
  - Servo, big expensive, but easy to control
    - Operate by varying orifice size -> varying flow rates of air into chambers
  - Solenoid are cheap and can use existing DC motor control to actuate
    - Use PWM control to actuate coil
      - With care to make sure pulse are long enough to completely close/open valve



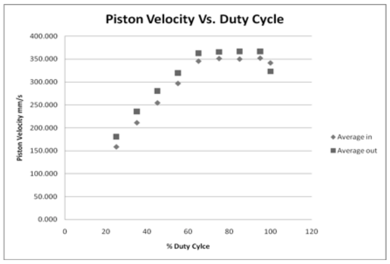
    - Opening and closing of valves controlled by coil

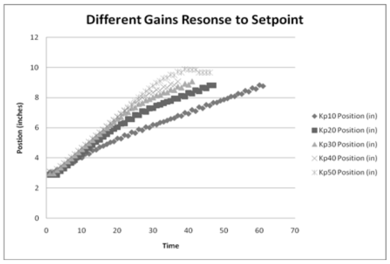
Experimental Setup

- Test-bed included:
  - Microcontroller to generate PWM signal, and sense position via linear transducer
  - Fixed pressure air supply, further controlled by an air regulator
  - 4-way 3-position pneumatic valve actuated by 2 24 VDC solenoids running at 0.25amps
- Initial test was to determine the open/close time of solenoid due to coils charging/discharging
  - This determined minimum duty cycle to use on valves



Pneumatics Results





- Experiment comparing piston velocity during extension and retraction based on different duty cycles
- Determined top limit on duty cycles is 65%
  - Combined with results from first experiment, range of duty cycles obtained

- Experiment comparing different proportional gains for driving piston from a set point at 3 inches to another at 9 inches
- These gains determined experimentally
- Gain of 50 shows overshoot
  - Hence gain of 40 selected

Placement Problem

Problem Setup:

- Given an area made up of N equally-sized square elements N $\{e_1 \dots e_n\}$

e_1			
			e_n

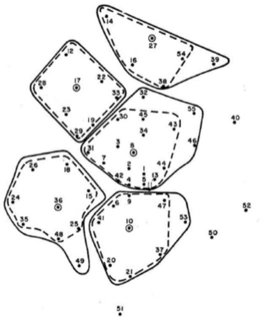
- Each element is a demand node (e.g. requiring surveying)
- Nodes with ISLANDS are considered supply nodes (limited)
- How should the ISLANDS nodes be placed so helicopters don't run out of fuel?

Assumptions

- Helicopter can be in only one element at a time
- Helicopter moves 1 grid element at a time using 1 of 2 traveling methods

Proposed Solution 1

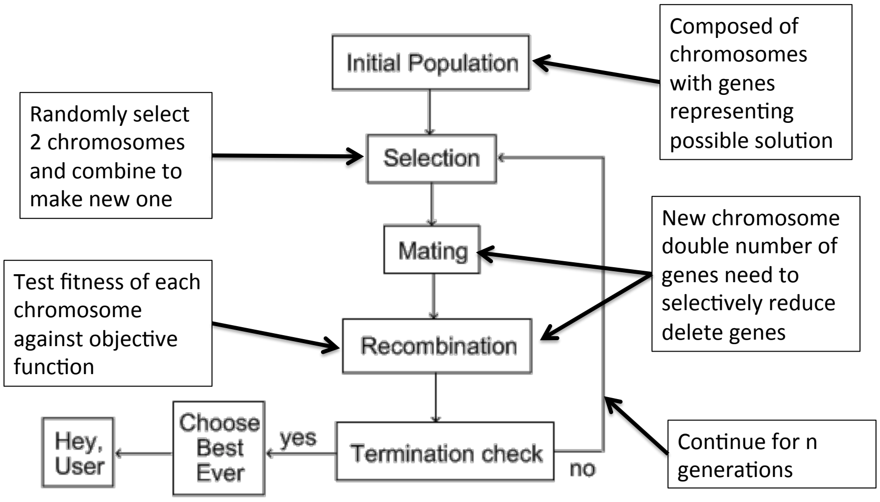
- In literature, similar problems have been solved using Maximal Coverage Location Problem in the field of resource allocation
  - Produces results of maximum % of area covered given *n* supply nodes
    - Nodes in outskirt sacrificed to increase area covered and reduce cost function



Proposed Solution 1 (cont.)

- P-median formulation guarantees 100% coverage but does not limit distance between nodes.
- For this work using a modified P-median formulation with additional constraint of distance limitation
  - These problems are NP-hard therefore using a heuristic genetic algorithm to solve
- Only considering one-way flight to specific node: not considering the nodes covered on way to demand node
  - Potential future work but out of scope of this project

Diversion: Genetic Algorithm



Composed of chromosomes with genes representing possible solution

Randomly select 2 chromosomes and combine to make new one

New chromosome double number of genes need to selectively reduce delete genes

Test fitness of each chromosome against objective function

Continue for n generations

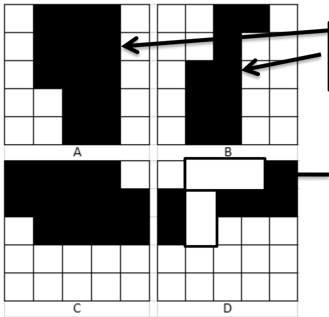
Distance Metric

- The cost function for p-median is distance dependent
  - Two different methods for calculating distance are used
    1. Manhattan distances derived by solving:

$$d_{sf} = |x_s - x_f| + |y_s - y_f|$$

The *n x n* distance matrix is calculated offline

2. A metric for coverage between two points, “zamboni” or “lawnmower”, also calculated offline



Zamboni/lawnmower distance range from 9-13

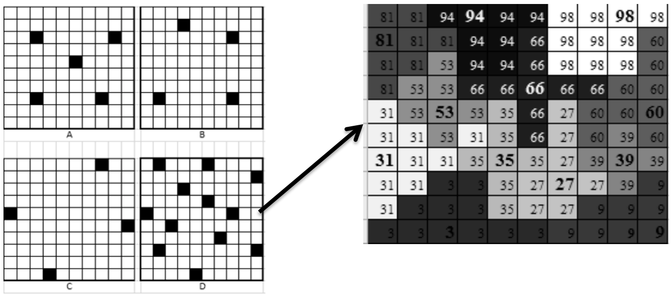
Manhattan distance is 5

Experiment

- Four experiments were performed using p-median formulation using modified genetic algorithm; all experiments performed on 10 x 10 grid
  1. No distance constraint, 5 ISLANDS nodes, using Hamiltonian distance metric
  2. 10 unit distance constraint (Manhattan distance metric)
     - Determine minimum number of ISLANDS nodes
  3. 10 unit distance constraint, using Zamboni/ lawnmower coverage distance metric
     - Determine minimum number of ISLANDS nodes

Results

- To determine minimum nodes needed, the algorithm was run assigning a cost function of infinity for results that violate distance constraint
  - Incrementally increasing number of ISLANDS nodes until feasible solution found

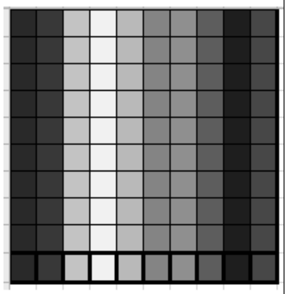


81	81	94	**94**	94	94	98	98	**98**	98
81	81	81	94	94	66	98	98	98	60
81	81	53	94	94	66	98	98	98	60
81	53	53	66	66	**66**	66	66	60	60
31	53	**53**	53	35	66	27	60	60	**60**
31	31	53	31	35	66	27	60	39	60
31	31	31	35	**35**	35	27	39	**39**	39
31	31	3	3	35	27	**27**	27	39	9
31	3	3	3	35	27	27	9	9	9
3	3	**3**	3	3	3	9	9	9	**9**

  - Does this make sense?
  - Is it useful?

Results Analysis

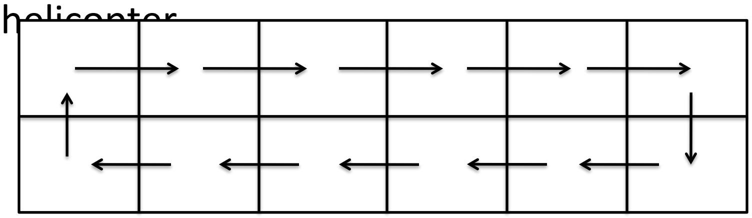
- Do these results make sense?
  - Yes, but not necessarily desired
- Why wasn't 10 ISLANDS solution found
  - Only 4 Possible solutions
  - With cost of 450
- Want solution with circular path
  - Not flying back over already observed areas



10 ISLANDS solution

Future Work On Placement Making Block

- Want to create blocks with circular path where path steps = flight endurance of helicopter



- Need to figure out how to shape and place these blocks

Questions?