Unmanned Aerial Vehicles:

* What
* Who uses them
* Categories
* How they are controlled
* Breakdown of UAS
  + Ground stations
  + Autopilot
  + Navigation system

Transition from getting to objectives/waypoints using guidance. . . here are some methods

**Vector Field Guidance:**

**Introduction to Vector Field Guidance:**

Vector field is a continuous guidance method that can be used for guiding a UAV to a singular point or for path following. Potential field and virtual force field guide to a singular point while avoiding obstacles by representing goals and obstacles as artificial attractive and repulsive forces respectively. Path following guidance can be achieved with Lyapunov and gradient vector field techniques that produce heading commands that converge and follow a path.

**Potential Field:**

Potential field is a robotic manipulator method that represents a robots workspace as a gradient potential of attractive and repulsive artificial forces \cite{khatib\_real-time\_1986}. A robot can be represented as a point mass initially located at a globally high potential that transitions to a goal located at a globally minimum potential. Obstacles are represented by a high potential that act as repulsive forces with an exponentially decaying strength as to only influence the robot when approaching the obstacle. The potential gradient can be depicted as a mesh such as that sown in Figure [].

Transitioning from one state to another traditionally occurs by executing three steps consisting of planning an obstacle free path, time parameterizing the path to consider basic dynamic constraints, and feed-back control to account for errors. Potential field is unique in that it combines path planning, trajectory planning, and control into a single system \cite{rimon\_exact\_1992}.

One of the inherent problems for potential field is the possibility to be trapped in a local minimum which is produced when multiple repulsive fields are placed in close proximity to each other. An example can be seen in Figure [] where a cluster of obstacles produces a local minimum that may prevent a robot from reaching the final goal state.

Several methods have been developed to eliminate local minimums through the use of navigation functions \cite{goerzen\_survey\_2010} and obstacle clustering \cite{liu\_virtual-waypoint\_2016}. Navigation functions relate kinematic constraints to the gradient potential to produce a bounded and local minimum free solution [rimon]. Clustering closely spaced obstacles into a single and equally repulsive obstacle prevents local minimum from forming. Typical clustering can be seen in Figure [].

Potential fields ability to avoid obstacles and combine path planning, trajectory planning, and control into a single computationally inexpensive system makes it an attractive motion control system for robots seeking a singular point. Fixed wing UAVs must maintain a minimum forward velocity and cannot converge to a single point, therefore may not be ideal for fixed wings.

**Virtual Force Field – Histogram Method**

Virtual force field is another artificial force method that calculates guidance to a known attractive goal while avoiding initially unknown repulsive obstacles.

**Lyapunov Vector Fields**

Lyapunov vector fields produce heading guidance that asymptotically converges and circulates along a path.

**Gradient Vector Fields**

Gradient vector fields produce heading guidance vectors whose integral lines asymptotically converges and circulates along n-dimensional curves and can be modified for obstacle avoidance.