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.

**Potential Field Addendum:**

Several inherent problems with potential field methods is the possibility to be trapped in a local minimum, failure to travel between obstacles, and corridor oscillations.

B and K developed the virtual force field (VFF) method, which is similar to potential field, intended for mobile robots transitioning from an initial state to a goal while avoiding initially unknown obstacles. VFF decomposes a robots workspace into discretized cells that contain an integer certainty value associated with the confidence that an obstacle occupies the cell. A global goal applies an artificial attractive force on the robot that pulls it closer to the goal. As the robot detects obstacles, the certainty value increases in the cell associated with the obstacles position. Cells apply artificial repulsive forces with magnitudes that depend on the certainty value and the distance to the cell.

\begin{figure}

\centering

\includegraphics[width=7cm]{PaperFigures/histogram}

\caption{Virtual force field histogram acting on a mobile robot}

\label{fig:histogram}

\end{figure}

The VFF histogram method was validated on a mobile robot platform using ultrasonic sensors in \cite{borenstein\_real-time\_1990} and \cite{borenstein\_vector\_1991}, avoiding obstacles and seeking a goal.

Several problems inherent to all potential field methods were identified while validating the VFF histogram method. Local minimum produced by closely spaced obstacles may create a situation where a robot settles into a lower potential prior to finding the global minimum. Additionally, closely spaced obstacles may also be difficult to pass between, shown in Figure []. Oscillations can also be experienced near obstacles or in narrow passages at high speeds, shown in Figure [].

Vector fields that direct a UAV to paths connecting waypoints have been developed using Lyapunov and gradient vector field techniques.

**Lyapunov Vector Fields**

Lyapunov vector fields produce heading guidance that asymptotically converges and circulates along a path passing through waypoints. Paths can be built from straight line and circular arc primitives taking UAV dynamic constraints into consideration. Nelson et al. introduced a vector field generation method for line primitives in \cite{nelson\_cooperative\_2005}. Farther away from the path, vectors are constant and point in the direction perpendicular to the path. Within a transition region the vectors begin to rotate and point more parallel to the path. Vectors on the path point directly in the direction of the path. Lyapunov vector fields for straight line and circular arcs are shown in Figure \ref{fig:nelsonlyapunov}.

Combining path primitives together can result in fairly complex paths such as that shown in Figure []. Each path primitive has a vector field associated with it and determining which field to use can be approached in two different ways. Fields from all of the primitives can be summed together similar to the attractive and repulsive forces in potential field. Second, fields can be selectively activated and deactivated based on the position of the UAV. Summing together vector fields, as pointed out in [], can result in several problems including dead zones, sinks, and singularities. Selectively activating each vector field as a UAV nears waypoints was used in [3 lyapunov papers].

Nelson's method was extended by Griffiths for curved path following and showed that the vectors asymptotically approach the curved path, shown in Figure \ref{fig:griffiths}. Constructing a vector field for an arbitrary curve in place of stitching together primitives has the advantage of not determining which field to activate and may allow for more complex paths.

\begin{figure}

\centering

\includegraphics[width=7cm]{PaperFigures/griffiths}

\caption{Lyapunov vector field approach curved path asymptotically}

\label{fig:griffiths}

\end{figure}

**Gradient Vector Fields**

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.

Paper format currently:

What vector field is (establishing terms)

Vector field produced by summing together multiple terms (Conv, Circ, TV)

What each term represents

Equation

Description of scalars and significance of weighting

* Direction
* Magnitude

Neglecting time varying paths

Convergence normal to the path

Circulation parallel to path

No definition at the center of the circle