Unmanned Aerial Vehicles (UAV’s)

Unmanned Underwater Vehicles (UUV’s)

and Swarms

Joseph T. Wunderlich, Ph.D.
Unmanned Aerial Vehicles (UAV’s)
Unmanned Aerial Vehicle “Global Hawk”

“Global Hawk provides high-resolution Synthetic Aperture Radar (SAR) and Electro-Optical/Infrared (EO/IR) imagery at long range with long loiter times over target areas. A Signals Intelligence (SIGINT) capability is also being developed. Potential missions cover the spectrum of intelligence collection capabilities to support joint combatant forces in worldwide peace, crisis, and wartime operations.”

“Signals intelligence (SIGINT) satellites are designed to detect transmissions from broadcast communications systems such as radios, as well as radars and other electronic systems......The United States operates four constellations of signals intelligence satellites”
UAV “Global Hawk” with its own SIGINT in 2010

Northrop Grumman Corp.

Radar detected by Global Hawk

Images and excerpt from: http://www.globalsecurity.org
UAV “Global Hawk”

An integrated sensor processor produces high-quality images from the radar and EO/IR sensor with the metadata required to support precision targeting.

The IMMC provides all of the functions necessary for Global Hawk to accomplish missions autonomously.

A Ku SATCOM system provides the ability to transmit imagery beyond line of sight via a wide-band satellite link.

The EO/IR and SAR unit captures radar and visible-light (0.4–0.8 microns) and medium-wave infrared (3.6–5.0 microns) image data.

Image from: http://www.emporia.edu/earthsci/student/graves1/project.html
UAV “Global Hawk”
Mission profile

From: http://www.emporia.edu/earthsci/student/graves1/project.html
UAV “Killer Bees”

Raytheon Corp.

“It has systems for land or sea launch, recovery and ground control. During the land-based test, KillerBee was recovered in a net mounted on a rapidly moving truck, demonstrating that the guidance system enables aircraft recovery from platforms moving at speeds similar to a naval vessel.

“...... represents a major upgrade to today's embedded airborne surveillance, reconnaissance and target acquisition capability.”

UAV “KillerBees”

Raytheon Corp.
NETCENTRIC WARFARE

image from: http://www.emporia.edu/earthsci/student/graves1/project.html
NETCENTRIC WARFARE

image from: http://www.emporia.edu/earthsci/student/graves1/project.html
“January 2, 2008 (AP) — The military’s reliance on unmanned aircraft . . . has soared to more than 500,000 hours in the air”
PEACETIME SWARM

1. DISTRESS CALL UTILIZING EMERGENCY BEACON
2. SEARCH & RESCUE SATELLITES
3. LOCAL USER TERMINAL
4. MISSION CONTROL CENTER
5. RESCUE COORDINATION CENTER

Search and Rescue

Figure 1: Simulation Output Window. Grey designates unknown area, robots shown: scout (black), medic (blue), fire-suppressant (red), and a light source (red).

Unmanned Underwater Vehicles (UUV’s)
Unmanned Underwater Vehicles “Aquabot”

Elizabethtown College student Steve Henderson prepares to put his robot submarine into Lake Placida in front of Leffler Chapel Wednesday. Below, Henderson checks the sub as it goes for a swim.
"Nereus will be the first autonomous vehicle to visit the 11,000m (36,089ft) Challenger Deep in the Pacific Ocean. Only two other vehicles have ever visited the spot before, both of them human operated."

Image and excerpt from: http://news.bbc.co.uk/2/hi/science/nature/8035499.stm
Developed at:
Woods Hole Oceanographic Institute
“Challenger Deep” is the name of the deepest place in the Mariana Trench. It is the deepest point in any of the Earth’s oceans (11,000 meters) (36,000 feet).
UUV “Nereus” Exploration

Image and excerpt from: http://news.bbc.co.uk/2/hi/science/nature/8035499.stm
UUV "Nereus" Exploration

VIDEO: http://video.aol.com/video-detail/sub-will-map-deepest-trenches/626778029
"A decentralized control scheme for large packs of unmanned underwater vehicles (UUV) is being proposed and investigated. This scheme is based on shared knowledge of a template, which includes operational plans, modes of operation, contingencies including the ability to adapt individual plans within the template to changing operational conditions, and the protocols for disseminating individual state, network, and command information between UUVs.”
Europa Rover Navigation

Possible course project

Maneuver on flat icy surface, then drill through 200 meters of ice

When water reached, either:
(1) Act as UUV, or
(2) Deploy a swarm of 100 10cm long UUV’s

Communicate with UUV’s if option (2) chosen

Communicate with base station that is also communicating with several orbiters and earth. The base station is also running a concurrent simulation to the rover’s real-time code and will be building a “GLOBAL” environmental map of the region of Europa being explored. This information should also be communicated back to the rover, -- and then to UUV’s if option (2) is chosen.
Swarms

Although Wunderbots are fully autonomous, the IGVC awards those who can respond to “JAUS” for Networked unmanned systems.

Figure 7: JAUS message header detailed structure [6]

Swarms

Wunderbot 4 Wireless Communication
by Jeremy Crouse (advisor: Dr. Wunderlich)


MORE ON THIS in COMPUTING LECTURES
Swarms

2012 Dr. Kumar TED Talk: https://www.youtube.com/watch?v=4ErEBkj_3PY

2013 Dr. Kumar Talk
https://www.youtube.com/watch?v=4ErEBkj_3PY

2014 TED Talk
by Magnus Egrstedt
https://www.youtube.com/watch?v=ULKyXnQ9xWA

Dr. Vijay Kumar, U. of Pennsylvania
(Dr. Wunderlich worked with Dr. Kumar at the AI DuPont Children's Hospital Applied Science and Engineering Lab, 1993-94)
So, the smaller you make it, the faster you can turn

\[ v \sim \sqrt{R} \]

\[ F = C_L A v^2 \sim R^3 \]

\[ m \sim R^3, \ I \sim R^5 \]

\[ a \sim 1 \]

\[ \alpha \sim \frac{1}{R} \]

SOURCE: https://www.youtube.com/watch?v=4ErEBkj_3PY

Dr. Vijay Kumar, U. PENN
If we start by looking at the displacement of an object (i.e. the distance from where it started to where it currently is) then when we look at the first derivative (by time) of displacement, (i.e. dividing the displacement of an object for how long it took to be displaced) we have calculated the object’s velocity.

\[ v = \frac{dx}{dt} \]

If we look at the rate of change of velocity, the second derivative (by time) of the object’s displacement (i.e. the rate of change of the rate of change of its displacement), then we have calculated the object’s acceleration.

\[ a = \frac{dv}{dt} = \frac{d^2x}{dt^2} \]

If we now look at the rate of change of acceleration, the third derivative of the object’s displacement (i.e. the rate of change of the rate of change of the rate of change of its displacement) then we have calculated the object’s jerk.

\[ j = \frac{da}{dt} = \frac{d^3v}{dt^3} = \frac{d^3x}{dt^3} \]

The first two derivatives of displacement, velocity and acceleration, are well known and reasonably well-understood by most people. But jerk is a little bit more difficult to understand. If we apply a force to an object it will accelerate, and we usually assume that this force is applied instantaneously. But this is not correct – it takes time to apply a force. As a result, the rate of acceleration will not be constant, and thus we have the jerk.

The fourth derivative of an object’s displacement (the rate of change of jerk) is known as snap (also known as jounce), the fifth derivative (the rate of change of snap) is crackle, and – you’ve guessed it – the sixth derivative of displacement is pop. As far as I can tell, none of these are commonly used.
In physics, jounce or snap is the fourth derivative of the position vector with respect to time, with the first, second, and third derivatives being velocity, acceleration, and jerk, respectively; hence, the jounce is the rate of change of the jerk with respect to time. Jounce is defined by any of the following equivalent expressions:

\[
\vec{s} = \frac{d\vec{j}}{dt} = \frac{d^2\vec{a}}{dt^2} = \frac{d^3\vec{v}}{dt^3} = \frac{d^4\vec{r}}{dt^4}
\]

The following equations are used for constant jounce:

\[
\begin{align*}
\vec{j} &= \vec{j}_0 + \vec{s}t \\
\vec{a} &= \vec{a}_0 + \vec{j}_0 t + \frac{1}{2} \vec{s} t^2 \\
\vec{v} &= \vec{v}_0 + \vec{a}_0 t + \frac{1}{2} \vec{j}_0 t^2 + \frac{1}{6} \vec{s} t^3 \\
\vec{r} &= \vec{r}_0 + \vec{v}_0 t + \frac{1}{2} \vec{a}_0 t^2 + \frac{1}{6} \vec{j}_0 t^3 + \frac{1}{24} \vec{s} t^4
\end{align*}
\]

where

- \(\vec{s}\) : constant jounce,
- \(\vec{j}_0\) : initial jerk,
- \(\vec{j}\) : final jerk,
- \(\vec{a}_0\) : initial acceleration,
- \(\vec{a}\) : final acceleration,
- \(\vec{v}_0\) : initial velocity,
- \(\vec{v}\) : final velocity,
- \(\vec{r}_0\) : initial position,
- \(\vec{r}\) : final position,
- \(t\) : time between initial and final states.
Swarms

Curved 12D space transformed into flat 4D space
\((x, y, z, \text{yaw})\), and then robot plans a trajectory through this 4D space. This is called a SNAP trajectory.

VIDEO SOURCE: https://www.youtube.com/watch?v=4ErEBkj_3PY

Dr. Vijay Kumar, U. PENN

Dr. Vijay Kumar, U. PENN

**Swarms**

- Decentralized control
- Local information
- Anonymity

![Diagram of drones](image)

\[ e_{ij} = x_i - x_j - s_{ij} \]

**LOCAL** Path Planning, but very complex! – and collective

SOURCE: [https://www.youtube.com/watch?v=4ErEBkj_3PY](https://www.youtube.com/watch?v=4ErEBkj_3PY)
Dr. Vijay Kumar,
U. PENN

Just give swarm Working Drawings, they Build!

SOURCE: https://www.youtube.com/watch?v=4ErEBkj_3PY
GLOBAL Path Planning,

Building an ENVIRONMENTAL MAP

SOURCE: https://www.youtube.com/watch?v=4ErEBkj_3P4