Quadcopters
History

• Also known as quadrotors
• First flying quadrotor:
  – 11 November 1922
  – Etienne Oehmichen

Image: blogger.com
History

• Quadrotors overtaken by helicopters due to workload of the pilot.
• Some experimental aircraft in the 1950’s
Now

• Increasingly more popular
  – Unmanned and small
  – Very maneuverable
  – Mechanically simple
  – Electronic stabilization

• Used for many applications
  – Photography, inspections, military … toys.
Definitions

• Roll, pitch and yaw
• Lift, drag, trust and weight
How does a quadcopter work?

• 2 pairs of counter rotating motors
• Roll, pitch and yaw control:
  – By varying motor speed
How does a quadcopter work?

• Roll and pitch
• Differential thrust

\[
L_1 + L_2 + L_3 + L_4 = L \\
(L_1 - \alpha) + (L_2 - \alpha) + (L_3 + \alpha) + (L_4 + \alpha) = L \\
(L_1 - \alpha) + (L_2 + \alpha) + (L_3 - \alpha) + (L_4 + \alpha) = L
\]

• Image: pitch forward
How does a quadcopter work?

- Yaw
- Differential torque

\[
L_1 + L_2 + L_3 + L_4 = L \\
T_1 + T_2 + T_3 + T_4 = 0
\]

- Image: rotate clockwise
How does a quadcopter work?

• Requires control of the motors
• Requires (electronic) stabilization:
  – Due to aerodynamic effects (vortices)
  – Differences between motors
  – Weight distribution

• To do this:
  – Requires speed controllers
  – Requires sensors and MCU
  – Understanding of the forces
How does a quadcopter work?

• System overview:

- GPS
- Flight controller with:
  - 3-axis gyro
  - 3-axis accelerometer
  - 3-axis magnetometer
  - Barometer
- Motor control
- RC Receiver
How does a quadcopter work?

• Main components:
  – Frame
  – 4 motors and their propellers
  – 4 speed controllers
  – Electronic stabilization
  – Battery
  – Receiver / other control
Pitch and roll

- Lift is always perpendicular to the flow direction, in our case the rotor plane.

- The gravity is always perpendicular to the ground.
Pitch and roll

• Lift and gravity with pitch and roll.
  – More lift required
  – Horizontal lift component provides thrust
  – When thrust overcomes drag the quadcopter moves.
Pitch and roll

- Gyro can sense the rotation around the pitch or roll axis.
  - Unit is rotation in degrees per second.
  - Integrating this yields pitch or roll angle.

- Accelerometer can measure gravitational components.
  - Pitch and roll angle can be calculated with three axes, two per angle (x,z) and (y,z).

- But....
Pitch and roll

• Why will this not work well in practice?
• Gyro’s (especially MEMS and Piezo):
  – Have a noisy signal
  – Have an offset (temperature, other effects)
  – This results in accumulating error in the integration.
  – Gyro’s can be used for short corrections
• Accelerometers:
  – The forces described previously are only in uniform linear motion.
  – In turns there are more forces due to horizontal lift component.
Pitch and roll

- When a plane/quadcopter turns it has to roll.
- This results in a horizontal and vertical lift component.
- The horizontal lift component gives a centripetal force.
- The weight and centrifugal force result in cancel out the lift (plane does not climb)
- This is more commonly known as g-force or load factor.
- This can be estimated by:

\[ g = \frac{1}{\cos(\alpha)} \]

For example 30 degree turn is 1.15g
- The accelerometer will measure this in the Z-axis, the other axes are 0.
Pitch and roll

• A quadcopter not only has this for roll but also for pitch in sideways movements.

• How to solve this:
  – Combine both the gyro and accelerometer information using sensor fusion.
  – This also makes measurements less sensitive to noise (for example due to vibration).
Yaw

• Turning around the top-axis.
• Usually compensated with gyros (short term compensation). Again: drift.
• For absolute yaw control: use a magnetometer
  – Basically an electronic compass.
Altitude

- Can be determined with distance sensors (e.g. ultrasone or infrared)
- Can be determined with barometric sensors
Local control

• Keeps the quadcopter stable.
• Requires sensor fusion
  – (Extended) Kalman filter
  – Direct Cosine Matrix
  – Linear complementary filter
Local control

• Various control schemes are used by open source projects:

![Diagram of various PID control structures](Image: IEEE: Build your own quadrotor)
Navigation

– GPS
– Visual servoing (markers)
– SLAM
– Lidar
TU/e designed quadcopter

- Optional to use, you can design your own quadcopter.
- 17 minutes flying time
- Max. 1 kilogram of payload
- Component list available
- Open source software (MultiWII)
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- MultiWII pro flightcontroller
- Flightcontroller communicates via bluetooth
- Can be flown manually with RC controller
- Sensors:
  - 3-axis gyro (*ITG3205*)
  - 3-axis accelerometer (*BMA180*)
  - 3-axis magnetometer (*HMC5883L*)
  - Barometer (*BMP085*)
  - GPS receiver (*MTK3329*)
  - 2 Ultrasound distance sensors (*HC-SR04*)
- Motor RPM counter
TU/e designed quadcopter

- Computer vision:
  - BeagleBoard XM
  - 5 Megapixel leopard camera (*LI-5M03*)
  - VGA webcam with wide-angle lens
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• Cost quadcopter including shipping
  – Approximately 500 dollar (385 euro)
    • Frame
    • 2 Batteries
    • RC transmitter and receiver
    • 4 Speed controllers
    • 5 Motors (1 spare)
    • Propellers (12 pieces)
    • Flight controller
    • Battery charger + power supply for charger
    • GPS
    • Bluetooth
    • 2 Distance sensors

• Beware of taxes and customs fees!
TU/e designed quadcopter

- Cost vision boards 310 dollar (240 euro)
  - Beagleboard XM
  - 5 Megapixel Leopard camera
    - Wide-angle lens
  - VGA webcam
    - Wide angle lens
  - WIFI dongle

- Beware of taxes and customs fees!
Questions?

• Thanks for your attention