Position Tracking of MFL Steel Floor Inspection Equipment inside Large Drained Out-of-Service Above-Ground Liquid Petrochemical Storage Tanks

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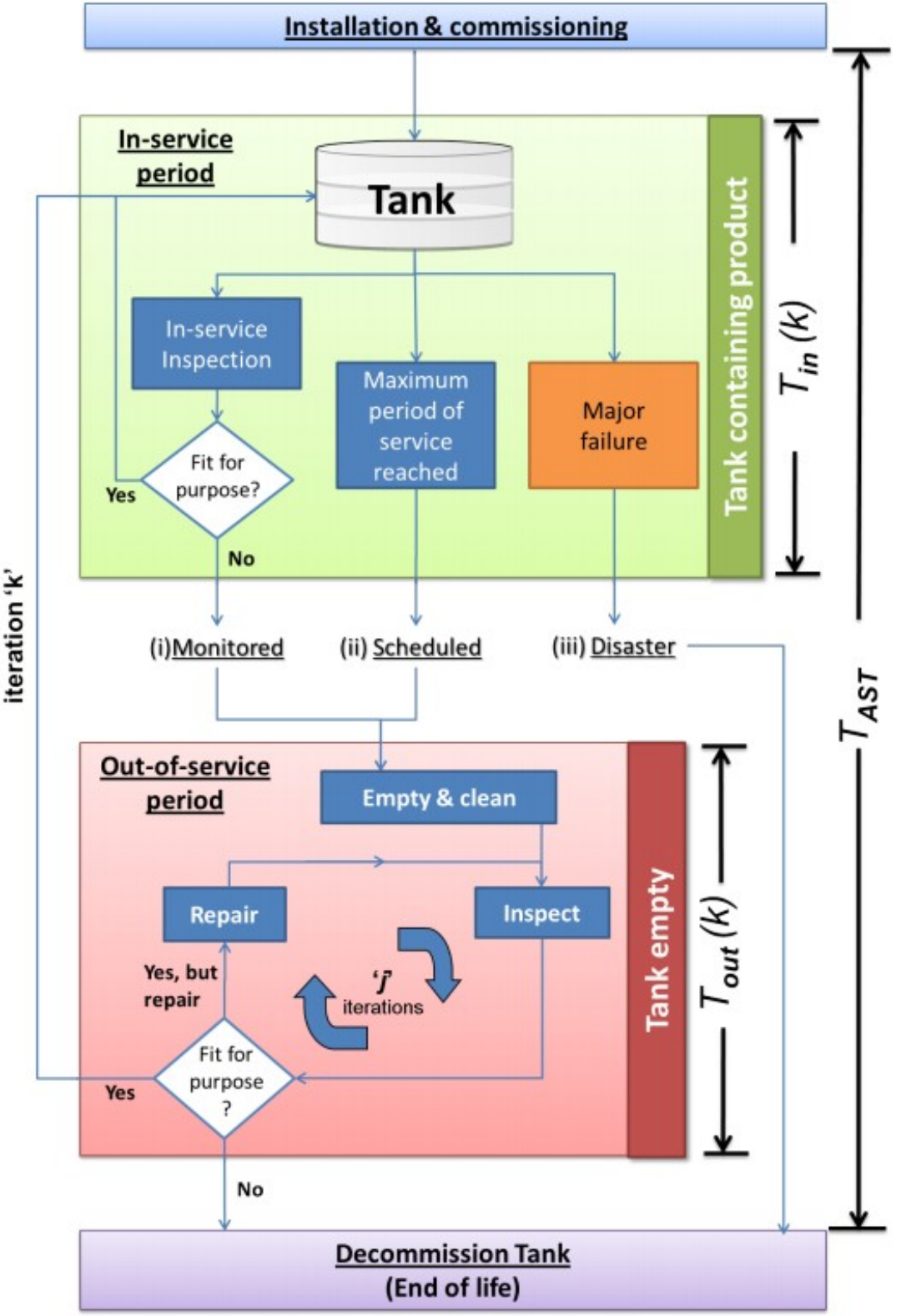
Above ground storage tanks

- Liquid petrochemicals
- Rubber lined steel plating
- +50 million litres capacity
- +80 meters in diameter

Maintenance regulations

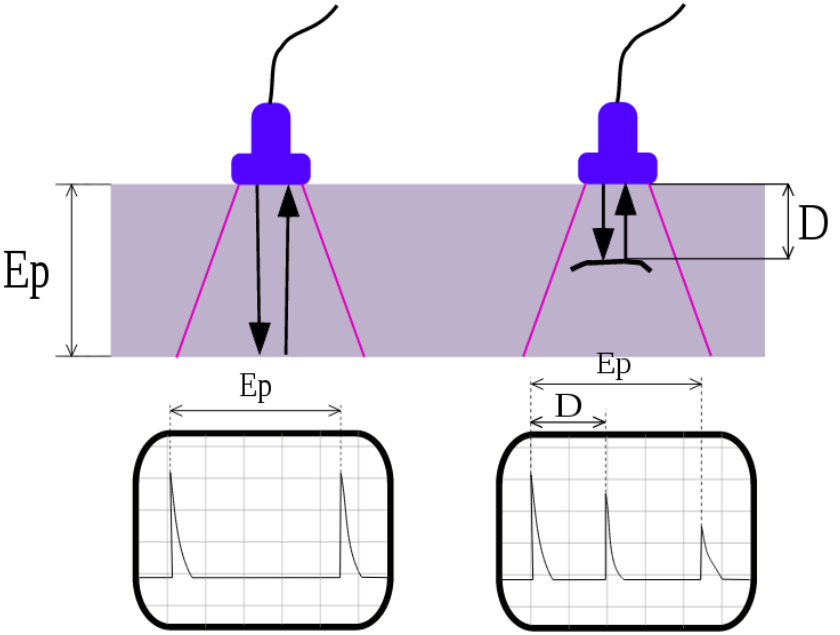
Australian Government
Department of the Environment

- Australia: maximum interval between inspections of 10 years
- USA: regulations divided between EPA and state governments
- Scotland: full inspection every 5 years



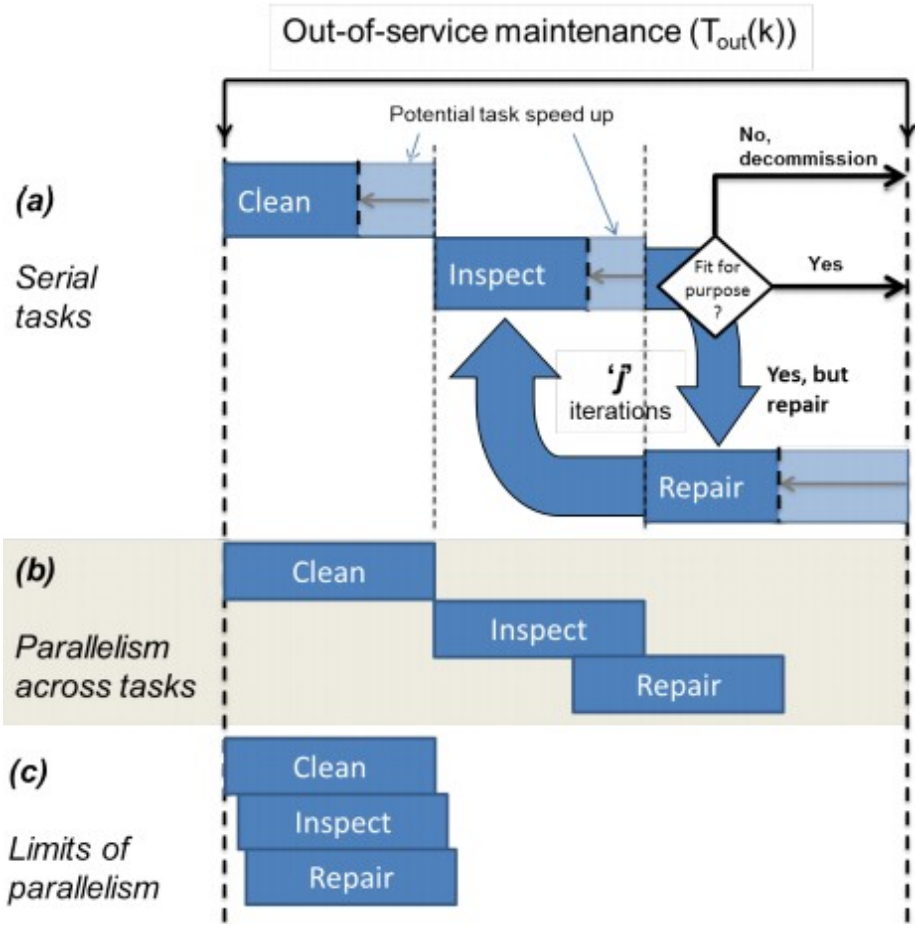
External inspection: Remote ultrasonic crawlers

- Similar to medical ultrasound
- Inspects all externally accessible surfaces
- Effective but slow (25mm/sec)



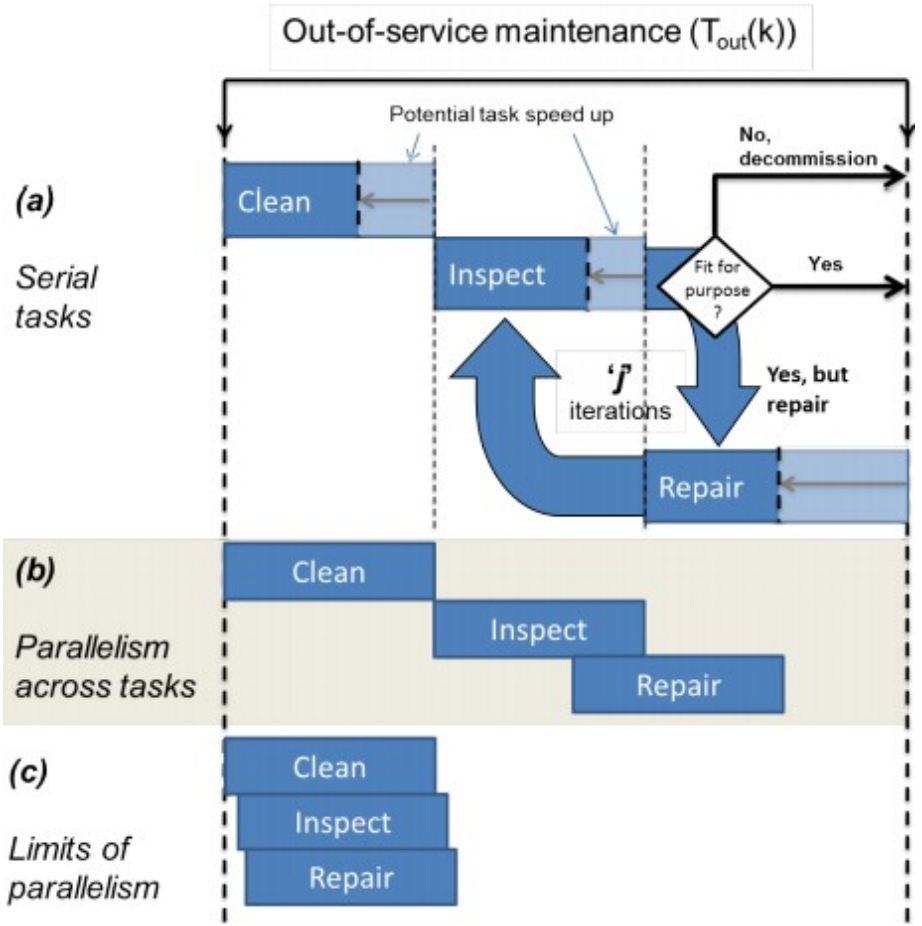
Internal maintenance

Plans to improve inspection: a) Present



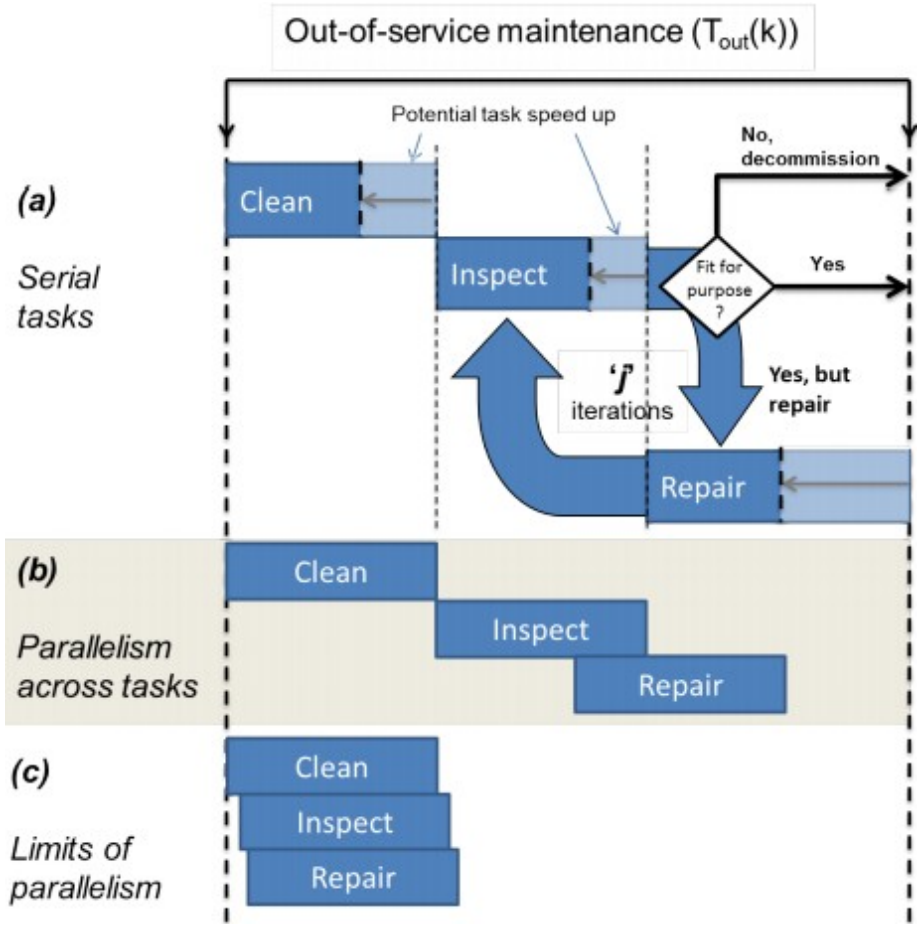
1) Tank is cleaned
2) MFL team inspects floor, produces analysis report
3) Ultrasonics team inspects problem areas, produces analysis report
4) Repair team gets to work on all internal surfaces,

Plans to improve inspection: b) Short-term



- Tank is cleaned first
- MFL, ultrasonics and repair teams in the tank at once
- Teams follow each other plate-by-plate
- Requires very fast analysis reports
- Inspection equipment must be upgraded with position tracking systems for faster defect mapping

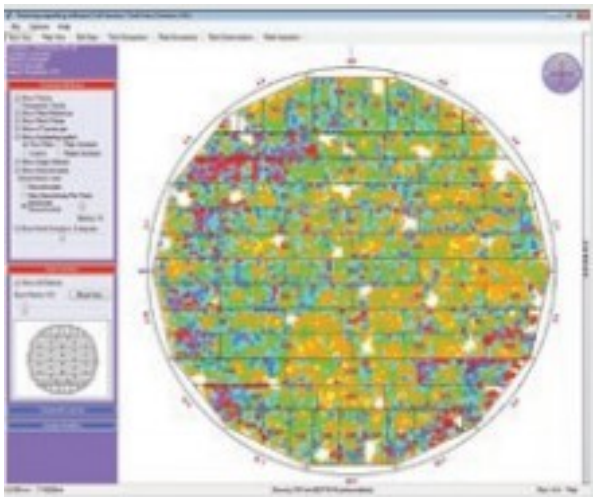
Plans to improve inspection: c) Long-term

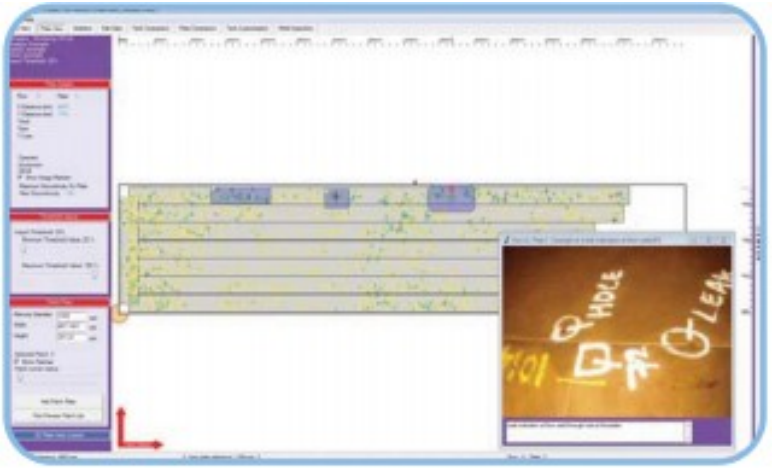


- All 4 teams in the tank at once
- Significant upgrade to all equipment required
- Inspection equipment needs major upgrade to inspect whole floor “in one run”
- SLAM - Simultaneous localization and mapping

Need position tracking system

- Inspection equipment must be upgraded with position tracking systems for faster defect mapping





Problems with current system

- Tracks straight line travel with tachometers on wheels
- Wheels slip over bumps
- Abutted plate joints cause problems
- “Hoover problem”, turning requires lifting
- Integral system, needs reference points to compliment

Accelerometers

- Accurate = Expensive
- Integral system

- Fits anywhere on MFL device
- No external reference devices

GPS

- No signal in tank / >4mm steel-lined cave

- Popular

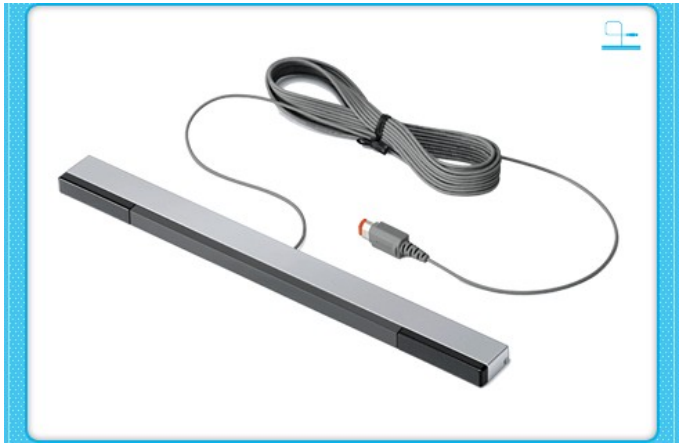
EM navigation (RADAR, LiDaR, LORAN, Ubisense)

- Far too inaccurate (best avaiable is Ubisense, 30cm)
- Δdist = c * Δtime
- c = 3x10^8 m/s (big)
- So Δtime (resolution) must be very small

- Speed of light (c) is constant
- Mature technology
- Robust and reliable in environment
- Off the shelf solutions avaiable

Cameras

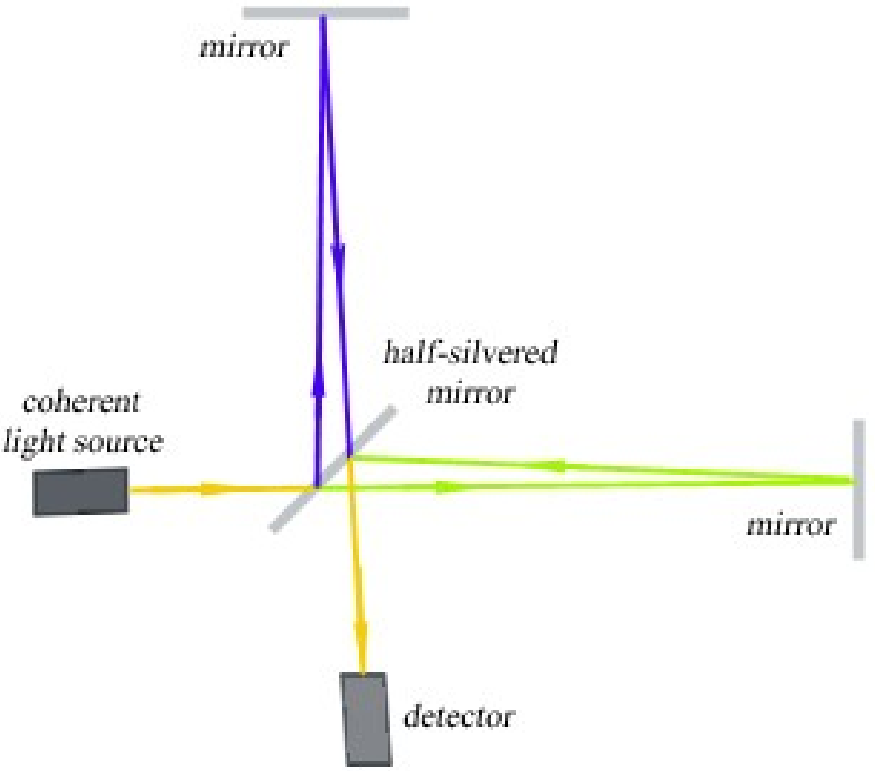
- Requires clean lens
- Sparks in camera image background
- Cannot compensate for beacons moving
- Must face forwards or use a special ring of evenly spaced LEDs



Interferometry

- Expensive
- Very clean & high quality mirrors

- Very very accurate



Measuring lines with tachometers

- Safety (trip wires + welding equipment)
- String can wobble

- Inexpensive
- Simple
- Portable
- Low power
- High resolution

Ultrasonic Echolocation (think Sonar)

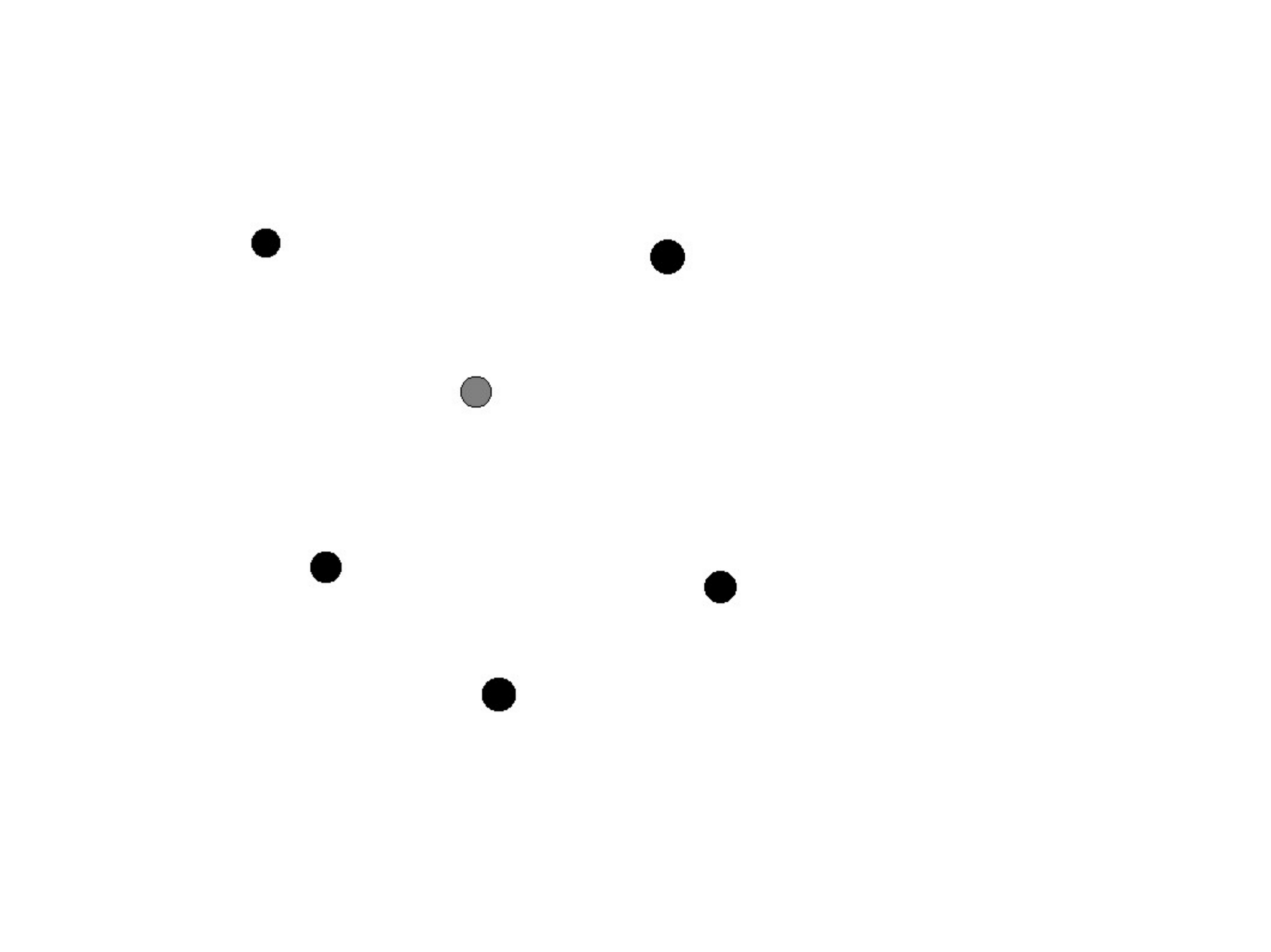
- Central plates too far from any walls
- Air movements distort measurements
- Less accurate over greater distance
- Air pressure unpredictable

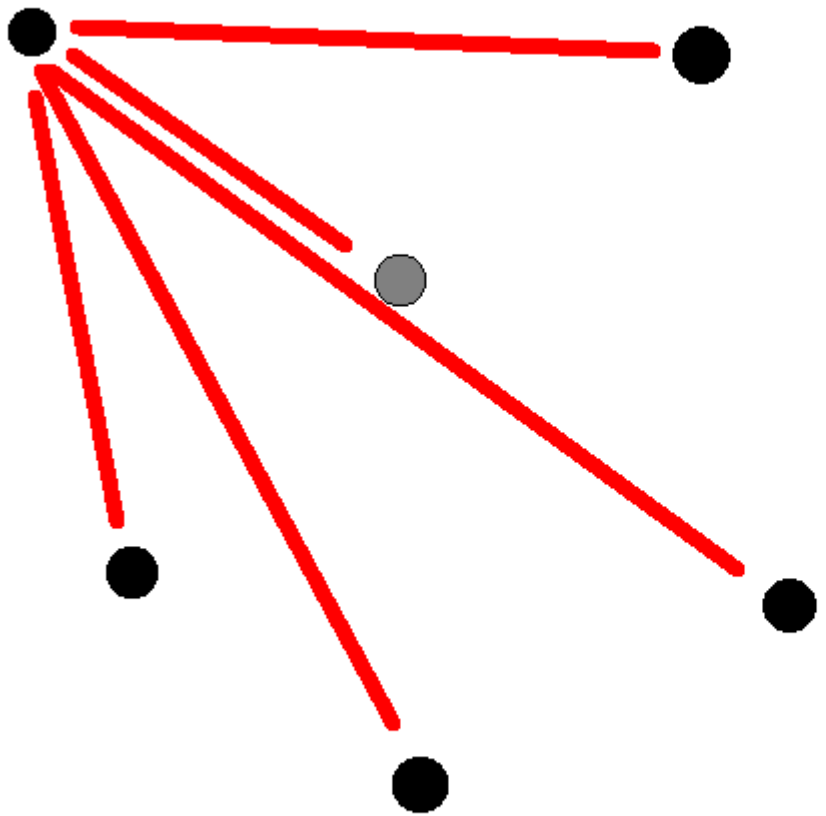
- Good accuracy (1mm – 100mm)
- Mature technology
- Flat, open terrain
- Thick flooring will not resonate
- Insulation reduces reflections

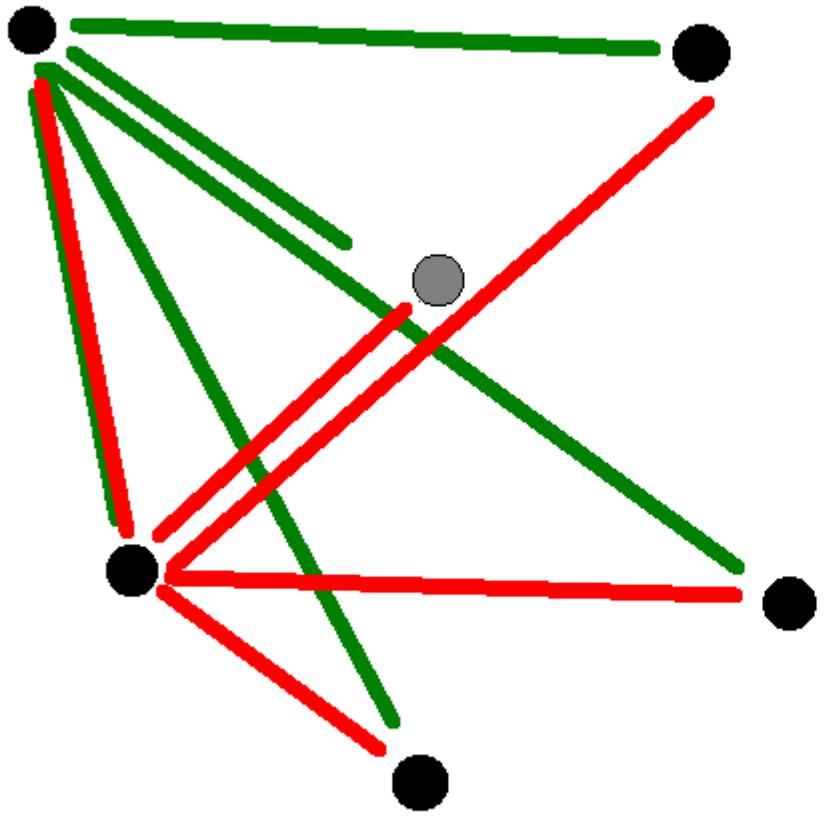
Ultrasonic Beacons

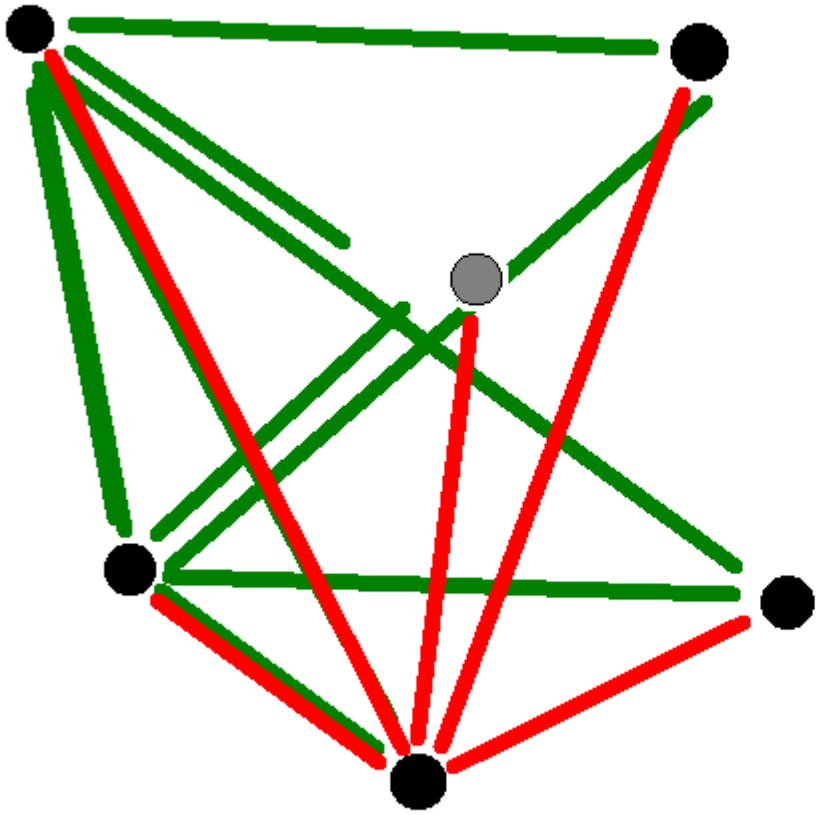
- Air movements distort measurements
- Air pressure unpredictable
- Requires beacons that can be knocked over

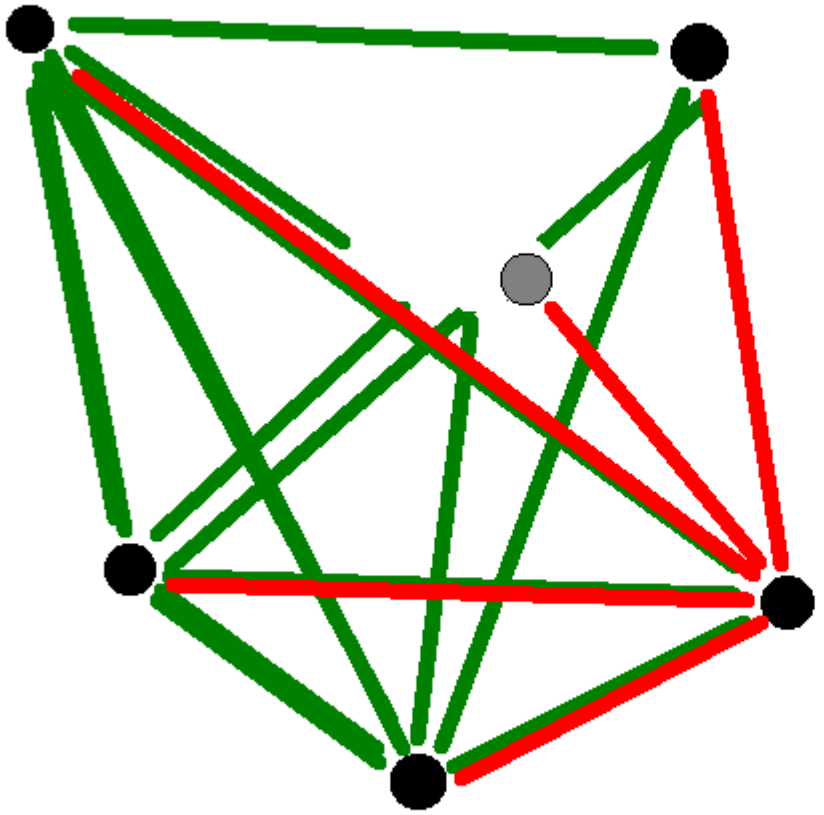
- previous slide cont.
- Beacons can be placed in vicinity of plate
- Beacons are inexpensive and portable
- Can compensate for beacons getting knocked over

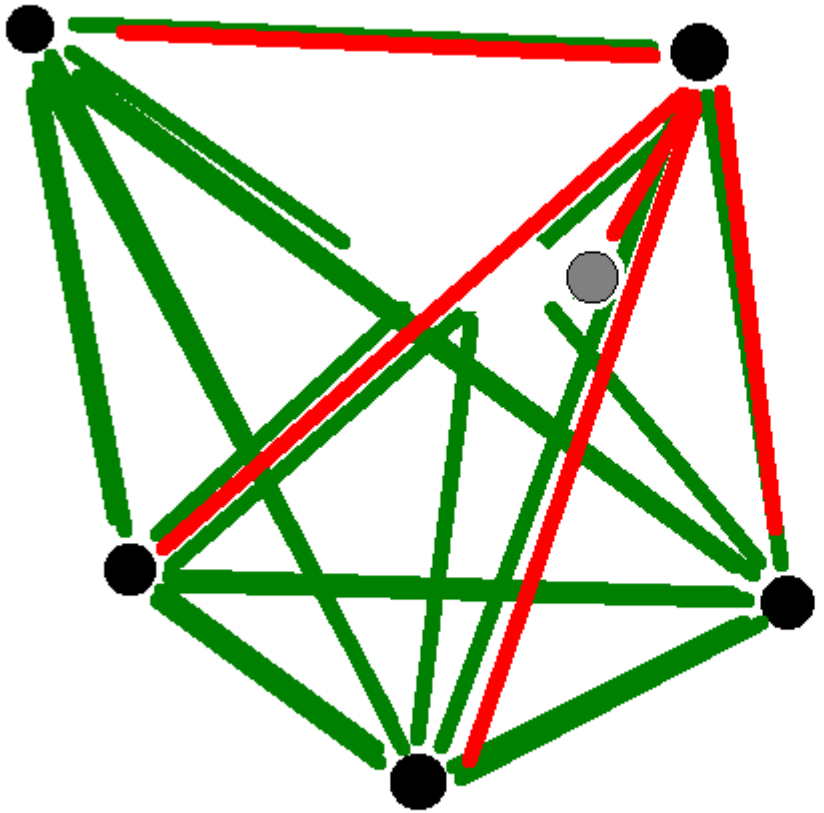


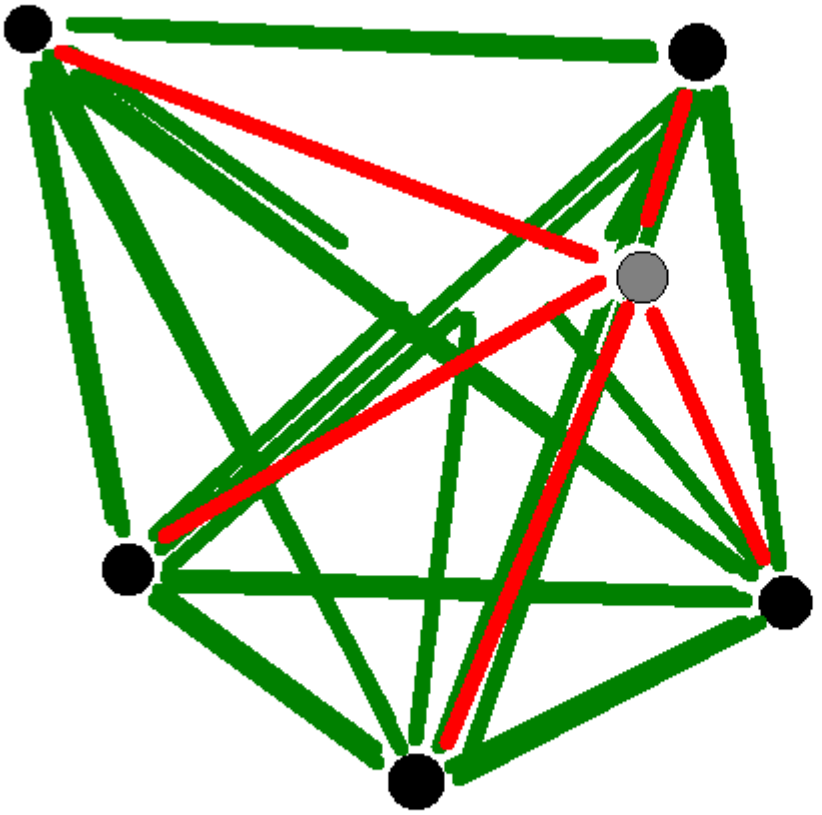


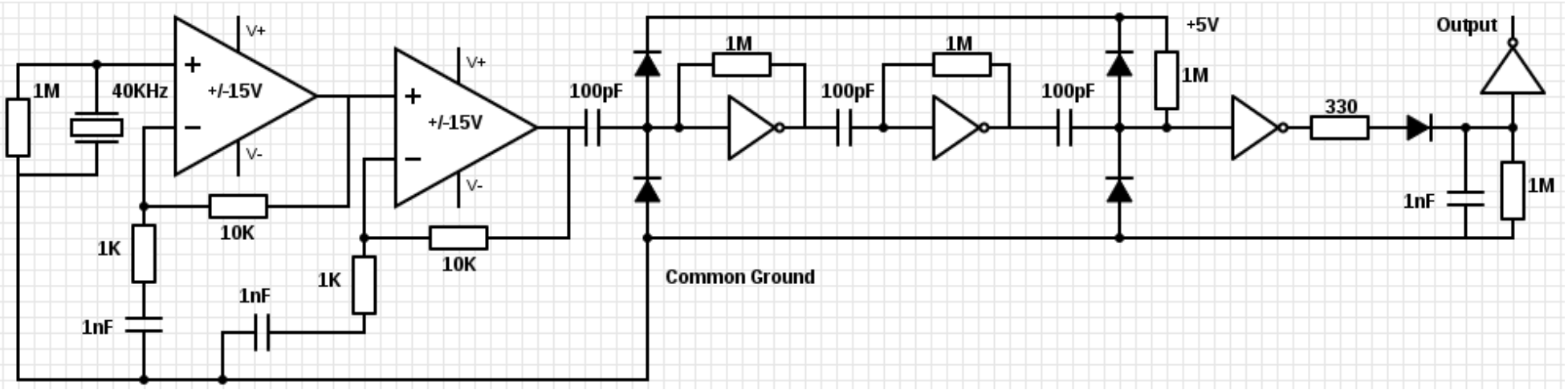


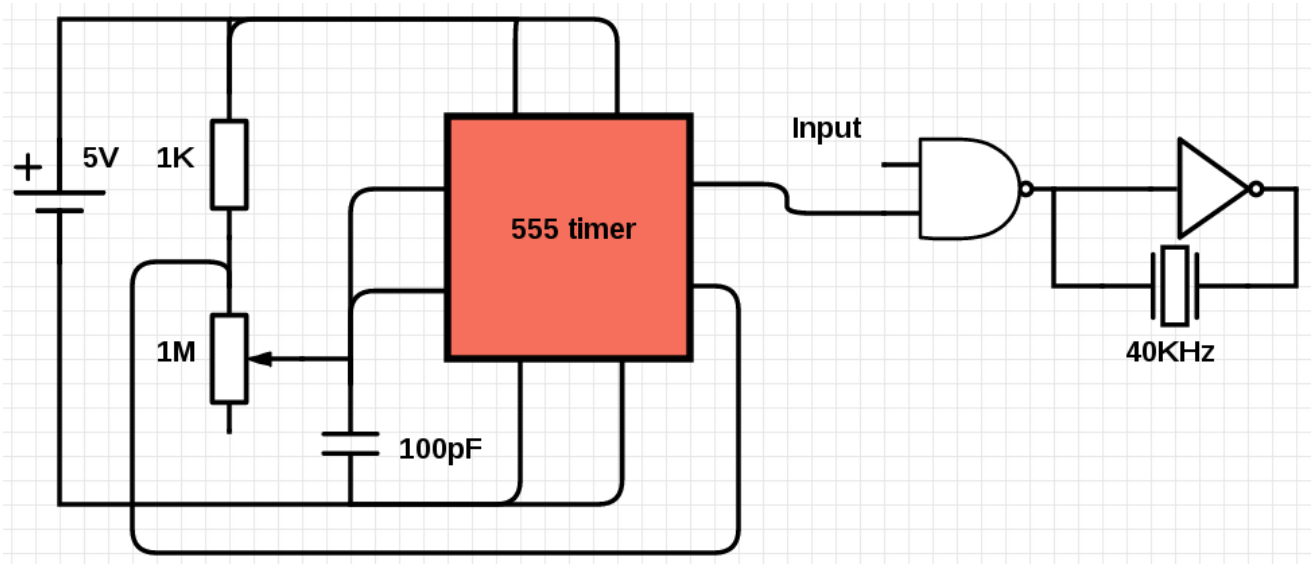









1M
40KHz
+/-15V
V+
V-
10K
1K
1nF
1nF
+/-15V
V+
V-
10K
1K
1nF
100pF
1M
100pF
1M
100pF
+5V
1M
330
Output
1nF
1M
Common Ground


5V
1K
555 timer
Input
1M
100pF
40KHz

```
//===Tx======================
const int ultrasound = 13;
const int trigger = 12;
void setup() {
  pinMode(ultrasound, OUTPUT);
  pinMode(trigger, OUTPUT);
}
void loop() {
  digitalWrite(ultrasound, HIGH);
  digitalWrite(trigger, HIGH);
  delay(10);
  digitalWrite(ultrasound, LOW);
  digitalWrite(trigger, LOW);
  delay(50);
}
```

```
//======================Rx===
const int ultrasound = 2;
const int trigger = 12;
const int counting = 13;
unsigned int counter[3] = {
  0   };
void setup() {
  pinMode(ultrasound, INPUT);
  pinMode(trigger, INPUT);
  pinMode(counting, OUTPUT);
  Serial.begin(9600);
  delay(100);
}
void loop() {
  while (digitalRead(trigger) == LOW) {
    digitalWrite(counting, LOW);
  }
  digitalWrite(counting, HIGH);
  while (digitalRead(ultrasound) == LOW) {
    counter[2]++;
    if (counter[2] == 0) {
      counter[1]++;
      if (counter[1] == 0)      {
        counter[0]++;
        if (counter[0] == 0) {
          break;
        }
      }
    }
  }
  digitalWrite(counting, LOW);
  for (int i=0;i<3;i++) {
    Serial.print('\t');
    Serial.print(counter[i]);
    counter[i] = 0;
  }
  Serial.print('\n');
  while (digitalRead(trigger) == HIGH);
}
```

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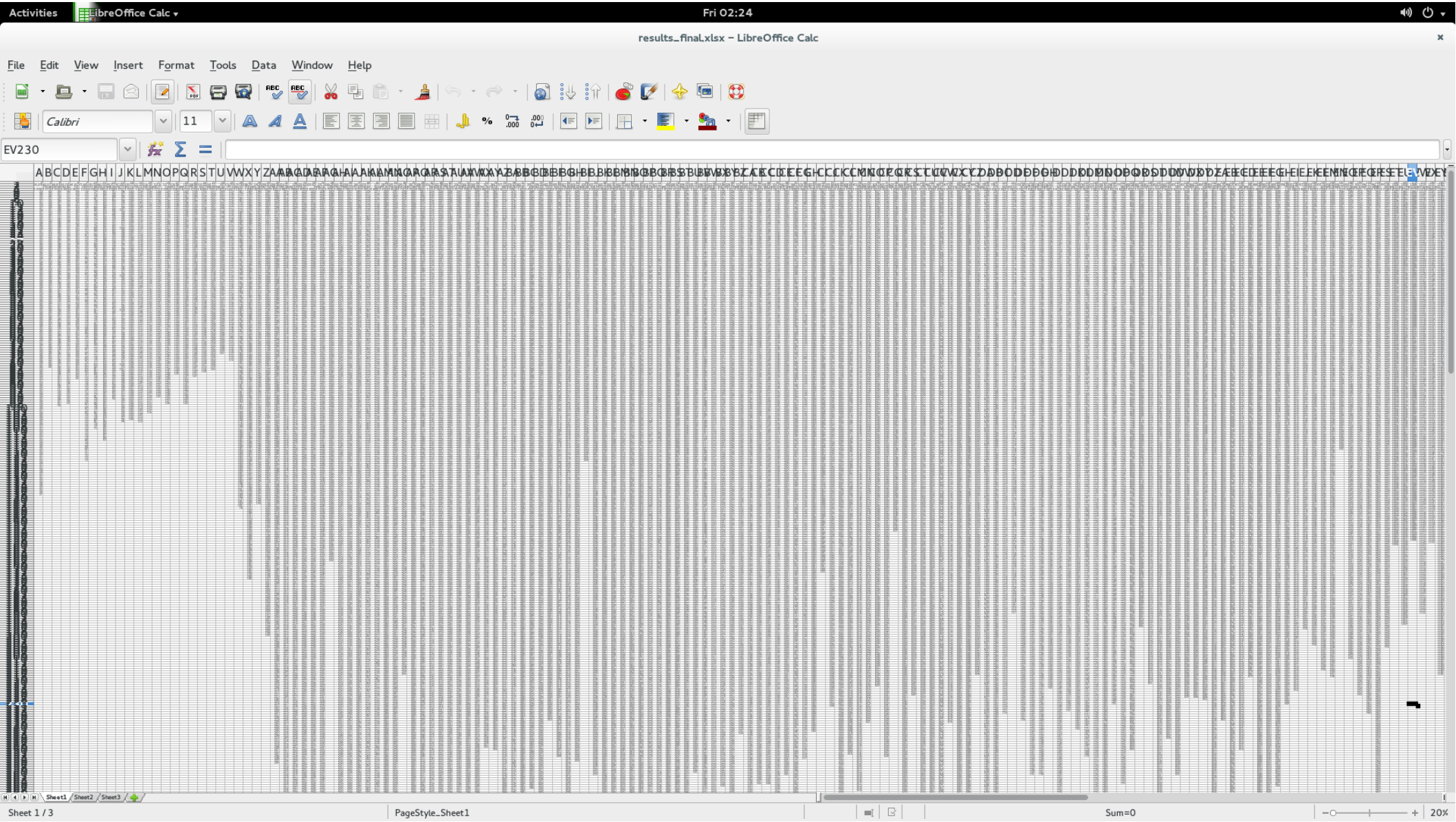
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Fri 02:24
results_final.xlsx – LibreOffice Calc
File Edit View Insert Format Tools Data Window Help
Calibri
11
EV230
Sheet1 Sheet2 Sheet3
Sheet 1 / 3
PageStyle_Sheet1
Sum=0
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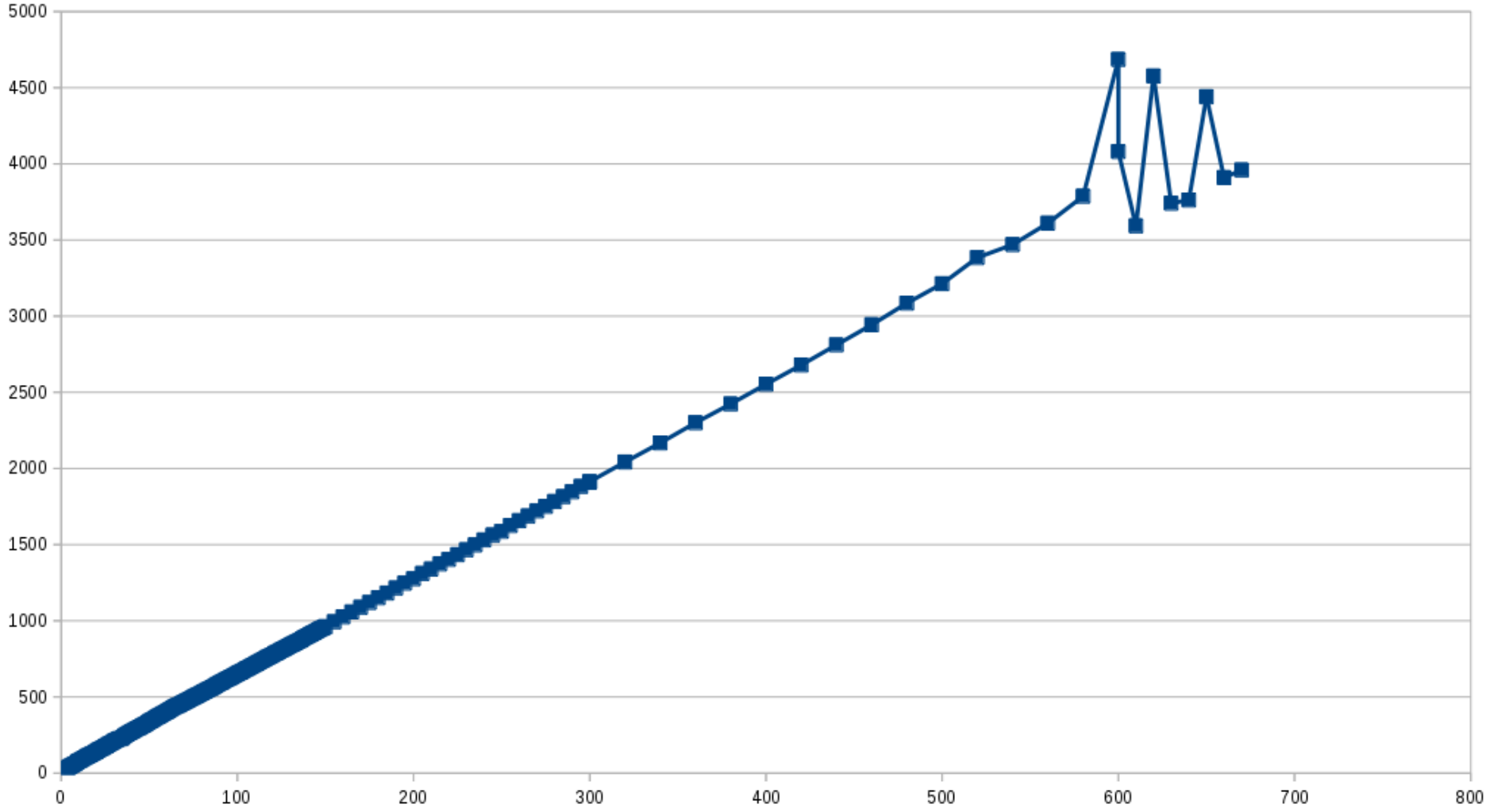
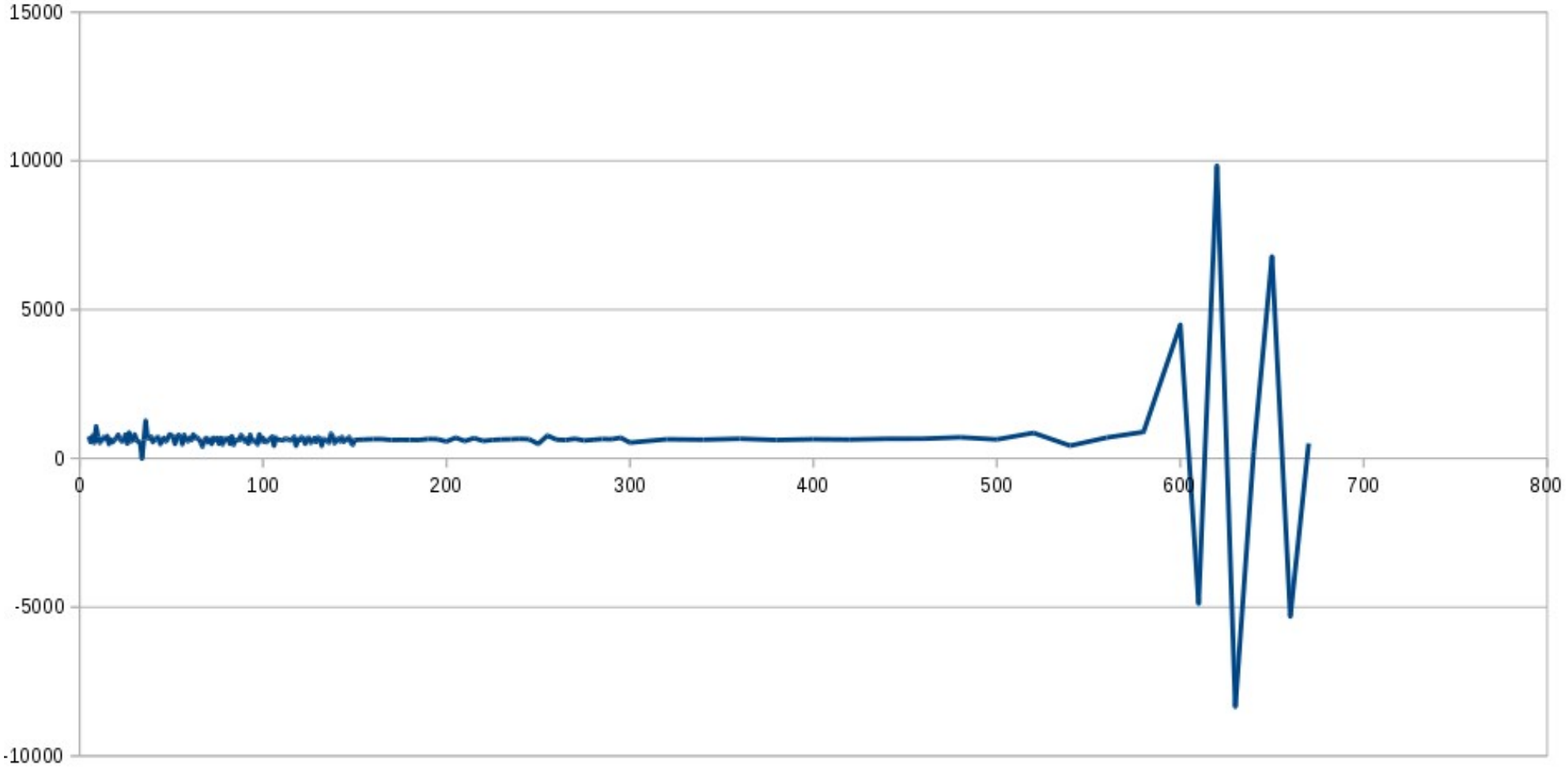
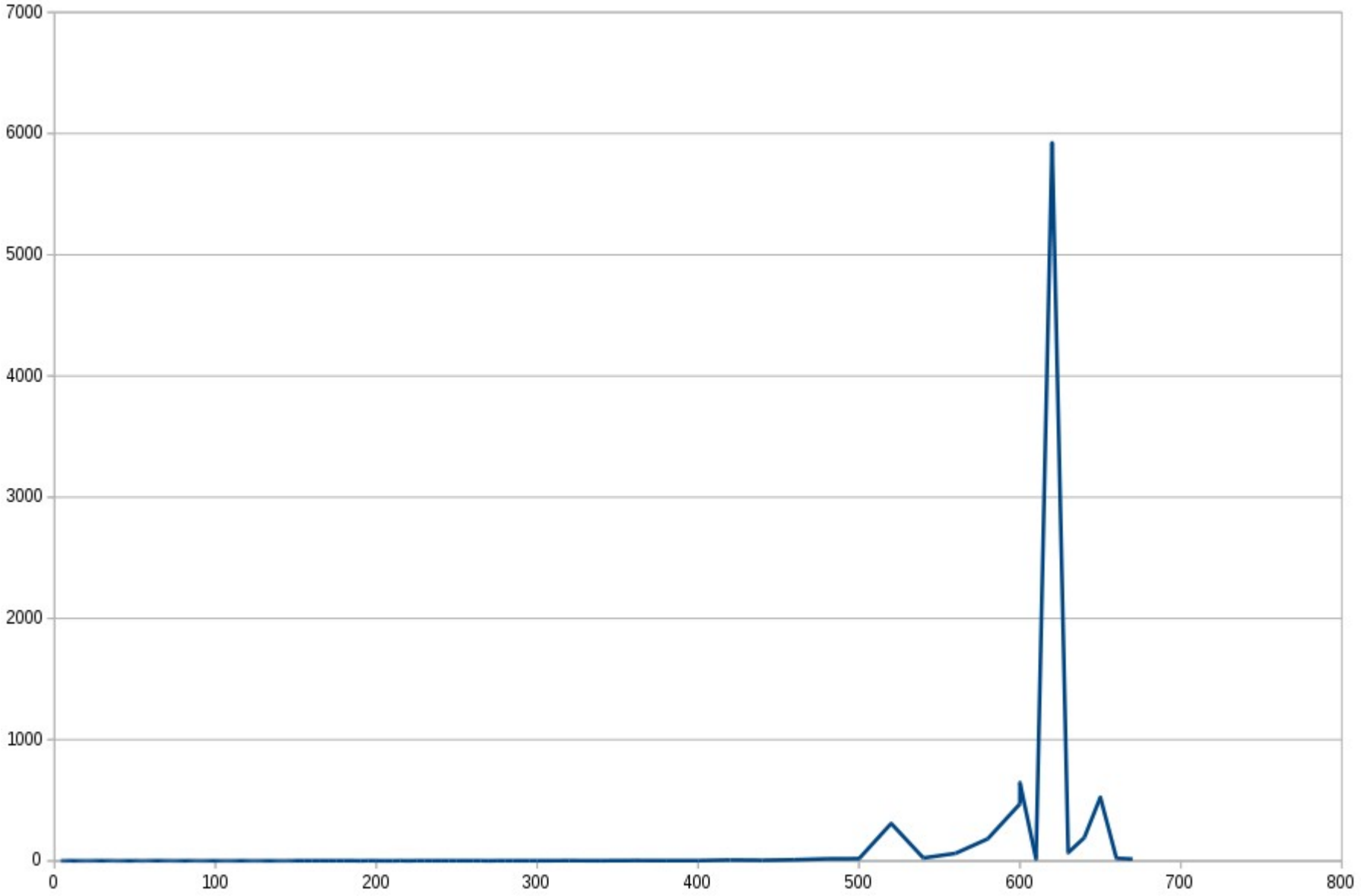
Average output (number of clock cycles) vs distance in cm



Linearity (difference between average readings) vs distance in cm



Standard deviation of clock cycles vs distance in cm



Conclusion

- Ultrasonic beacons show promise.
- Kalman filters make everything better.
- Further investigation of this system inside the tank is required.
- Longer term solutions could potentially render this system obsolete, however, system was only ever intended to act as a short term middle step in development.