The Lighthouse positioning system

Overview

Goal

An understanding of how the Lighthouse system works.

Virtual Reality (VR) gaming system

- Invented by Valve around 2014
- The first product, Vive, was manufactured by HTC
- Consumer grade

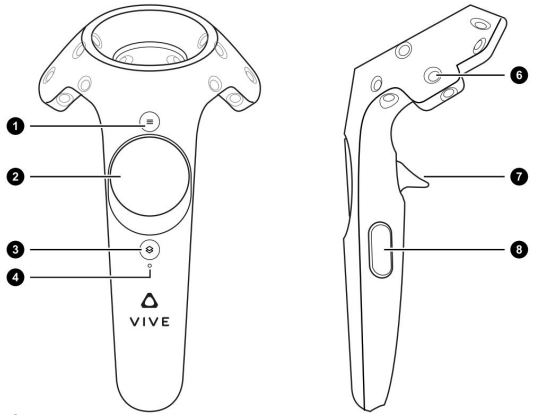
Note: images in this presentation from vive.com, Vive manuals, www.roadtovr.com, github.com (DoNck), Ben Jackson / Valve

Vive

- Headset
  - Stereo display
  - Front-facing camera
- Controllers
- Base stations (x2)
  - 360-degree play area tracking coverage
  - Wireless syncing
- External PC
  - High precision pose tracking of headset and controllers
  - Image rendering for headset

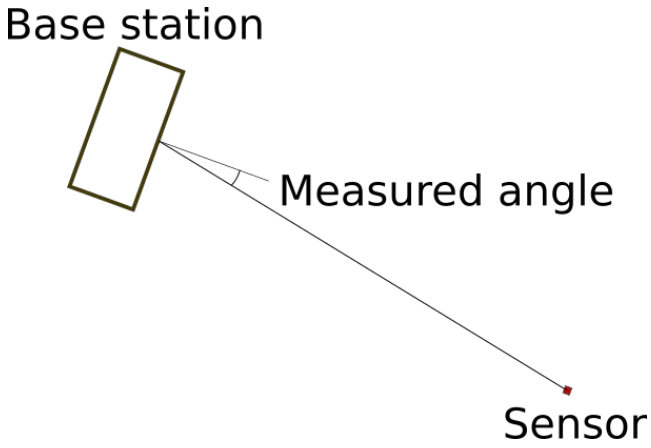
Vive basic functionality

- Base stations transmit light that can be used for positioning. Only transmitting, no knowledge of other devices
- Controllers and headset have light sensors that detect light from the base stations
- Information is sent to the PC for processing and position estimation



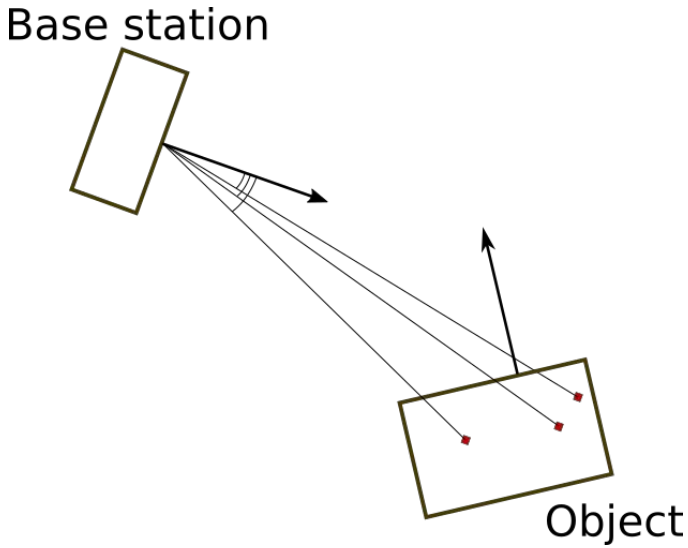
Vive Base station

- The name of the base station is Lighthouse
- Enables a device to measure the angle between base station and sensor (horizontally & vertically)
- Very high precision (sub millimeter)
- 1 base station is enough for positioning
- No official information - reverse engineering
- Lighthouse V1 and V2



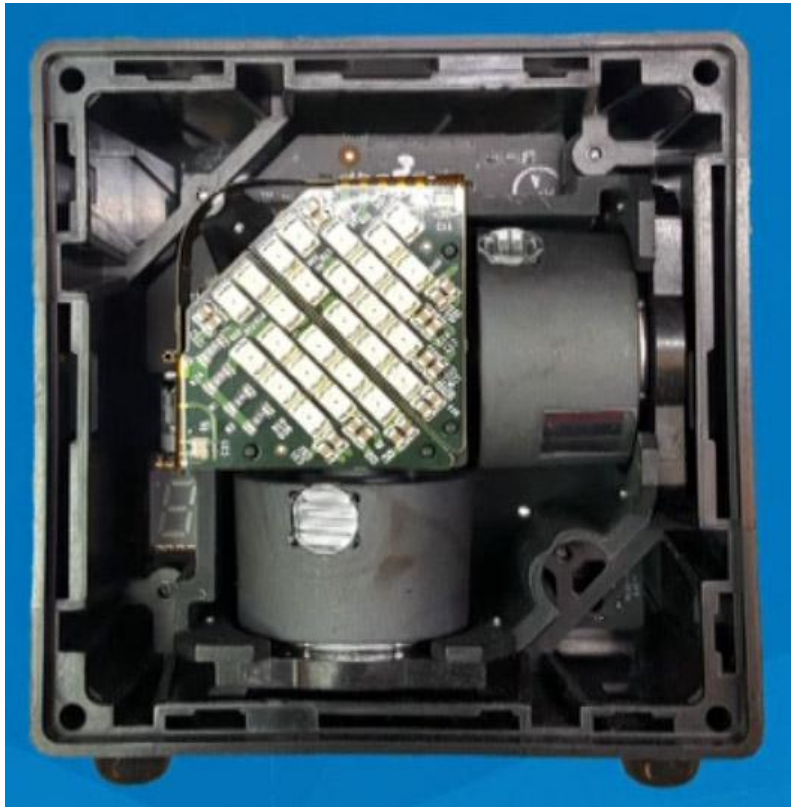
Multiple sensors

- With multiple sensors on an object it is possible to calculate
  - Distance from base station to object
  - Orientation relative to base station of object
- With knowledge of base station position and orientation it is possible to calculate
  - Object position
  - Object orientation



Lighthouse V1 - principles

- Flash (LEDs)
- Two spinning rotors with lenses
  - Horizontal
  - Vertical
- The lenses create thin layer of light that sweeps through the space when the cylinder rotates
- Rotors spin at 60Hz



Lighthouse V1 - sweeps

- The flash is fired before each sweep
- The light sensor is first triggered by the flash and secondly when it is hit by the sweep
- The time between the tiggers can be converted to an angle
- Total sweep frequency 2 X 60 = 120 Hz

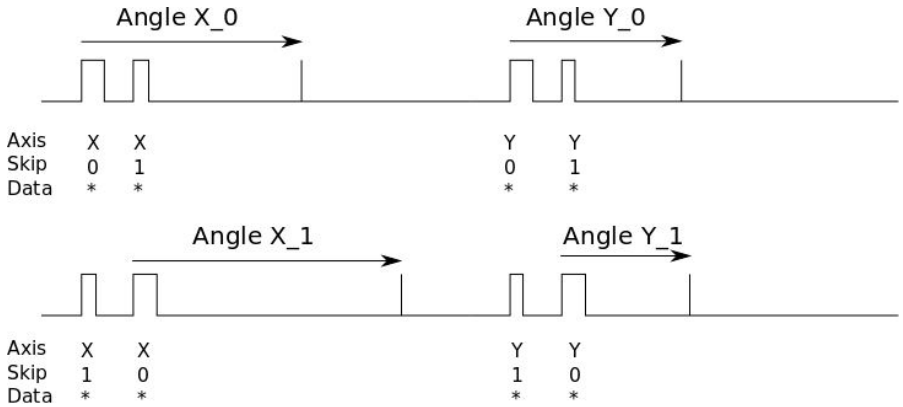
Note: Sweep directions are not correct in image

Lighthouse V1 - two base stations

- Lighthouse V1 supports 2 base stations for better coverage and less risk of occlusion
- Base stations are synchronized using cable (better) or light
- The base stations alternate and turn off their lazers every second revolution
  - Base station 1 do both horizontal and vertical sweeps
  - Base station 2 do both horizontal and vertical sweeps
- Total system sweep frequency 120 Hz

Lighthouse V1 - Flash modulation

- Both base station transmits omnidirectional synchronisation flashes
  - Master flashes first, then slave
  - The length of the synchronization flashes encodes 3 bits
    - Which base station that is active
    - Horizontal or vertical sweep
    - Calibration data
- The active base-station transmits the Sweep



Lighthouse V1 - Calibration data

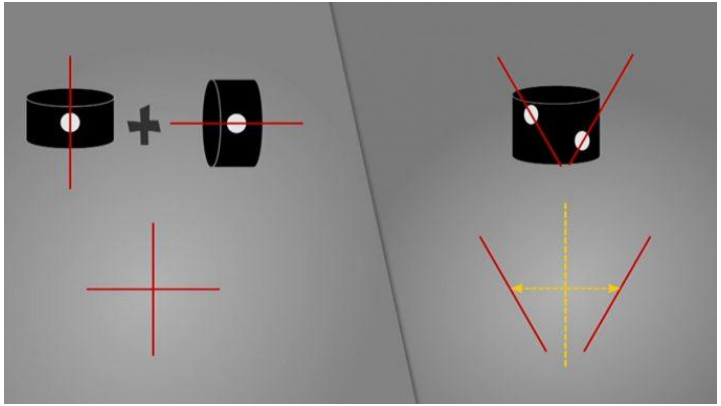
- Contains compensations for imperfections when manufactured
  - Lens error
  - Mechanical alignment
- Applied to the measured angles ⇒ more correct angle
- Not fully understood, work in progress

Lighthouse V2 - principles

- Only one rotor with 2 lenses
- Lenses rotated, form a V of light
- Lenses offset on rotor
- No synchronization flash
- Time information encoded in the light
- Unsynchronized base stations
- Supports 16 base stations ⇒ cover larger area
- Less knowledge than V1, work in progress

Lighthouse V2 - the light planes

- Light planes at -30, +30 degrees
- More complex relationship between sensor trig times and horizontal and vertical angles
- Time to center line
  - horizontal angle
- Time between triggers
  - Related to vertical angle
  - Trigonometric formula



Lighthouse V2 - light modulation

- The light is modulated and contains time information
- 6 MBit/s Manchester modulation
- When the sweep passes a light sensor, the sweep has a certain width and the sensor can record a few bits of the modulated light
- LFSR - Pseudo random sequence
  - Sequence reset every revolution
  - 20 or more are bits required to uniquely identify where in the sequence we are
- We know the bitrate and can calculate the time since sequence start
- By knowing the rotation rate we can calculate the angle of the rotor when the sensor recorded the bits

Lighthouse V2 - Base station identification

- Each base station uses different pseudo random sequences
- By identifying which bit sequence we got, we can identify the base station
- There are 16 pseudo random sequences
- The sequence that is used is a configuration parameter in the base station that must be known

Lighthouse V2 - rotation rate

- The rotation rate is around 50 Hz
- Different for each base station to minimize interference
- Configuration parameter that must be known (probably not transmitted)

Lighthouse V2 - calibration data

Similar to Lighthouse V1 with some added data. Work in progress...

The light sensor

- Works both with Lighthouse 1 and 2
- Demodulation
- Envelope follower
- Edge detection

The Lighthouse deck

- 4 sensors
- FPGA
- Handles precise timing for signals from the light sensors
- Preprocesses signals to offload the main CPU
- Higher level of information sent to the Crazyflie for further processing

Calculating the position

- Current solution finds closest point between two vectors
  - Base station position and orientation must be known, called geometry data
  - Calibration by using Vive hardware
- Requires 2 base stations
- Result is a point in space, no orientation
- Simple and robust

Future positioning methods

- Position with one base station only
- Better utilization of the kalman estimator by feeding partial information to it
- Full pose (position + orientation)

Future functionality

- Better use of calibration data
- Calculate base station geometry data using Crazyflie
- Lighthouse 2 support

Conclusions

- V1
  - 2 rotating drums
  - Limited to 2 base stations
- V2
  - One rotating drum with two planes
  - More than 2 base stations