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Department of Biomedical Engineering

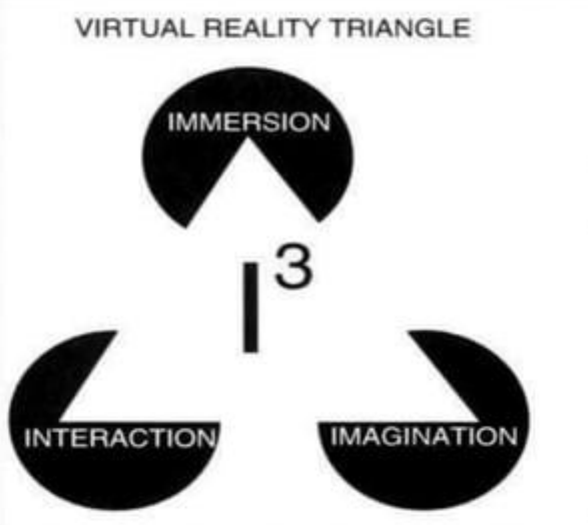
Course Name: 19BMT401 – Virtual Reality in Medicine

IV Year : VII Semester

Unit I –INTRODUCTION

Topic : Three-dimensional position trackers, navigation and manipulation, interfaces and gesture interfaces

1.1 THE THREE I's OF VIRTUAL REALITY



THE THREE I's OF VIRTUAL REALITY

- It is clear from the foregoing description that virtual reality is both interactive and immersive.
- These features are the two I's that most people are familiar with.
- There is, however, a third feature of virtual reality that fewer people are aware of .
- Virtual reality is not just a medium or a high-end user interface, it also has applications that involve solutions to real problems in engineering, medicine, the military, *etc.* These applications are designed by **virtual reality developers.**
- The extent to which an application is able to solve a particular problem, that is, the extent to which a simulation performs well, depends therefore very much on the **human imagination, the third "I" of VR.**
- Virtual reality is therefore an integrated trio of immersion interaction and imagination, as shown in Figure 1
- **The imagination part of VR refers also to the mind's capacity to perceive nonexistent things.**
- The triangle in Figure 1, for example, is easily "seen" by the reader, yet it only exists in his or her imagination.

1.3 EARLY COMMERCIAL VR TECHNOLOGY

- The first company to sell VR products was **VPL Inc., headed by Jaron Lanier** [VPL, 1987].
- In 1992 this company produced the **first sensing glove**, called as **Data Glove** (Figure 1.6a).
- The **standard interfaces** are **keyboard** and **mouse** of that time (and still today) .
- The VPL Data Glove **represented a quantum improvement in the natural way. one could interact with computers.**
- **Its fiber-optic sensors allowed computers to measure finger and thumb bending, and thus interaction was possible through gestures.**
- Its **drawbacks** were high price (thousands of dollars), lack of tactile feedback, and difficulty in accommodating different hand sizes.

1.3 EARLY COMMERCIAL VR TECHNOLOGY

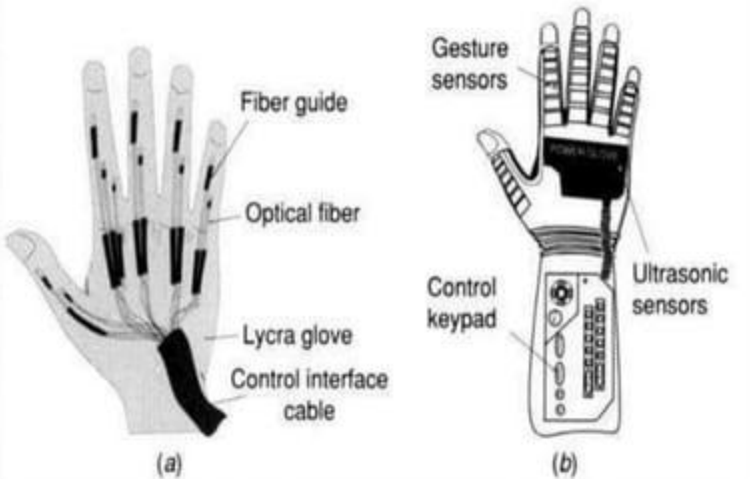


Fig. 1.6 Early sensing glove technology: (a) the VPL Data Glove; (b) the Power Glove. From Burdea [1993]. Reprinted by permission.

1.3 EARLY COMMERCIAL VR TECHNOLOGY

- Shortly after the appearance of the VPL Data Glove, the **game company Nintendo** introduced the much **cheaper Power Glove**, shown in Figure 1.6b.

Power Glove:

- It uses **ultrasonic sensors** to measure wrist position relative to the PC screen and **conductive ink flex** sensors to measure finger bending.
- In 1989 almost one million such new game consoles were sold in a consumer frenzy that was later repeated with the introduction of **Sony Play Station**.
- The **downfall** of the Power Glove was **lack of sufficient games that used it**, such that by 1993 its production had stopped.
- The first commercial head mounted displays, called **Eye Phones**, were introduced by VPL in the late 1980s.

1.3 EARLY COMMERCIAL VR TECHNOLOGY

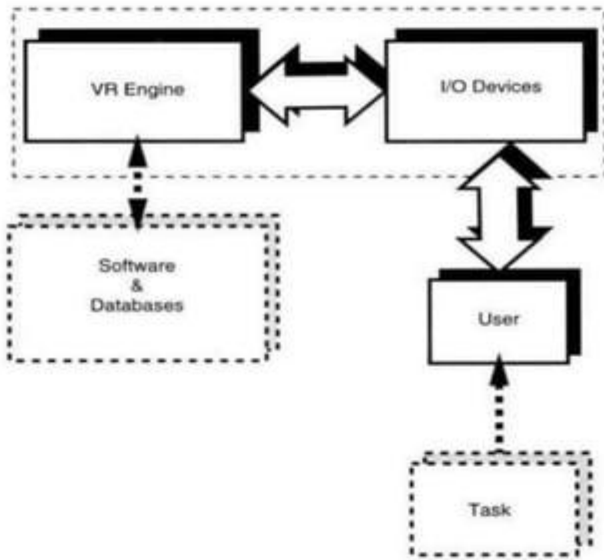
- These HMDs used **LCD** displays to produce a **stereo image**, but at **extremely low resolution** (360 x 240 pixels), such that virtual scenes appeared blurred. **Other drawbacks** were **high price** ($11,000 each) and **large weight** (2.4 kg).

- Researchers now had an initial set of specialized hardware with which to start developing applications.

- **However, they first had to solve various integration issues as well as develop most of the required software from scratch.**

- The idea of a turnkey VR system originated with VPL as well. Its RB2 Model 2 offered a rack assembly housing the Eye Phone HMD interface, the VPL Data Glove Model 2 electronic unit, a spatial tracking unit for the HMD, a design and control workstation, as well as connections to an SGI 4D/3 10 VGX graphics renderer and to an optional 3D sound system.

1.5: The 5 Classic Components of VR System



The five classic components of a VR system

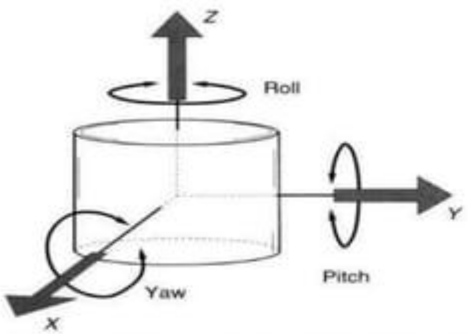
Input Devices: 3D Position Trackers

Many computer application domains, such as navigation, missile tracking, robotics, CAD, education and VR require knowledge of real time position and orientation of moving objects within some frame of reference.

These applications have varying requirements in terms of parameters such as measurement range, precision and temporal update rates.

3D Position Trackers

- A moving object in 3D space has six degrees of freedom, three for translations and three for rotations
- If a Cartesian coordinate system is attached to the moving object as illustrated in Fig. below and then its translations are along the X, Y, and Z axes.

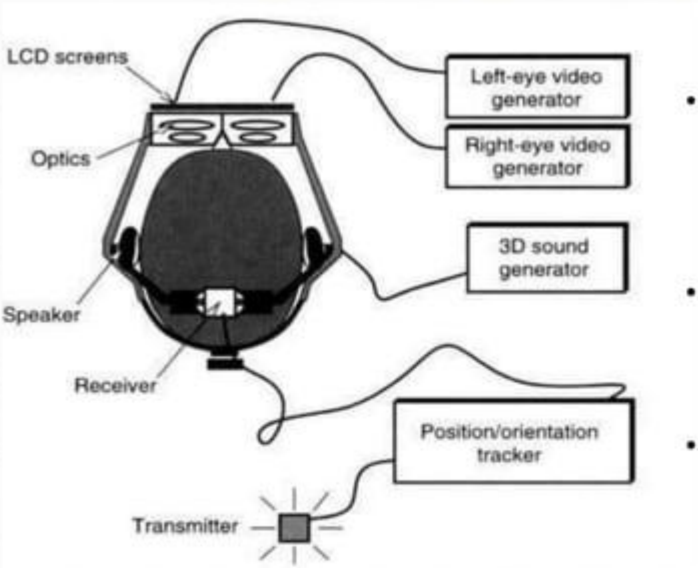


Object rotations about these axes are called yaw, pitch, and roll, respectively. These define a dataset of six numbers that need to be measured sufficiently rapidly, as the object may be moving at high speed.

3D Position Trackers

- The special-purpose hardware used in VR to measure the realtime change in a 3D object position and orientation is called a **tracker**.
- Virtual reality applications typically measure the motion of the user's head, limbs or hands, for the purpose of view control, locomotion, and object manipulation
- A newer tracker application in VR is for the control of an avatar, or virtual body, mapped to the user. In the case of the head mounted display illustrated in Fig. next slide

3D Position Trackers



A 3D magnetic sensor in a HMD

- the tracker receiver is placed on the user's head, **so that when the posture of the head changes, so does the position of the receiver.**
- The user's **head motion is sampled by an electronic unit and sent to a host computer**
- The computer uses the tracker data to calculate a new viewing direction of the virtual scene and to render an updated image.

3D Position Trackers

- This scene is then converted to National Television System Committee (NTSC) video signals displayed by the two LCD screens.

- Without the 3D head tracker the computer could not have changed the spatial view to match the user's head posture, and the "immersion" sensation would have been lost. Hence the trackers plays an major roll in VR.

- Another VR sensorial modality that uses tracker information is 3D sound, which in Fig, is presented through headphones

3D Position Trackers

- Tracker data allow the computer to co-locate sound sources with virtual objects the user sees in the simulation. This helps to increase the simulation realism and the user's feeling of immersion in the synthetic world
- The measurement accuracy requirements for the 3D sound application are much less stringent than those needed by the graphics feedback.
- the visual acuity is higher than the auditory localization acuity, and auditory depth perception is even weaker in humans.
- It is therefore necessary to look at tracker performance parameters in order to match their measurement capabilities to different sensorial channel requirements and available budgets.

Tracker Performance Parameters

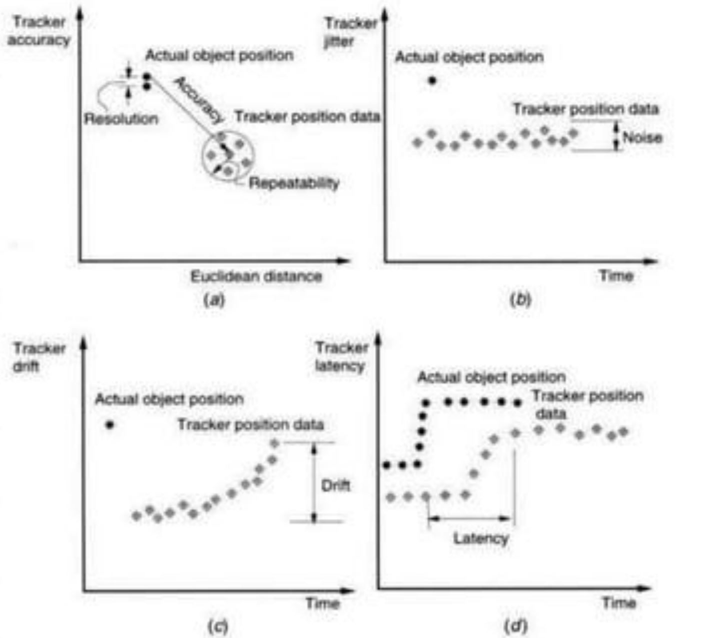


Fig. 2.3 Tracker performance parameters: (a) accuracy; (b) jitter; (c) drift; (d) latency.

All 3D trackers, regardless of the technology they use, share a number of very important performance parameters, such as accuracy, jitter, drift, and latency. These are illustrated in Fig

Tracker accuracy represents the difference between the object's actual 3D position and that reported by tracker measurements.

- The more accurate a tracker, the smaller this difference is and the better the simulation follows the user's real actions. Accuracy is given separately for tracking translation (fraction of a millimeter) and rotation (fraction of a degree).
- Accuracy is typically not constant and is degraded with distance from the origin of the reference system of coordinates.
- The distance at which accuracy is acceptable defines the tracker operating range or work envelope.
- At the tip of the tracker accuracy vector shown in Figure 2.3a is the sphere of tracker repeatability. This encloses repeated measurements of a real object stationary position. Repeatability depends on tracker jitter.

Functions of Tracker :

- Typically the tracker measurement, communication, rendering, and display loops are asynchronous, each operating at a different speed.
- An efficient way to reduce system latency is to synchronize the tracker and communication loops with the display loop called as **generation lock, or genlock**.
- With genlock the computer receives tracker data just in time and overall system latency is reduced (but not eliminated).
- Whether genlock is used or not, a way to reduce system latency is to **use fast communication lines.**
- If the sensor data are sent to the host computer continuously, then the tracker operates in streaming mode. This is most appropriate for fast-moving objects or when the application requires a quick response to a change in the moving object's position.

Tracker update rate

- **Definition:** The tracker update rate represents the number of measurements (datasets) that the tracker reports every second.
- The larger the tracker update rate, the better is the dynamic response of the simulation.
- Depending on the tracker technology, update rates vary between 30 and 144 datasets/sec or more.
- If the same tracker electronics is used to measure several moving objects, then the sampling rate suffers due to the multiplexing effect.
- Figure 2.4 illustrates the update rate of two types of trackers.

Tracker update rate

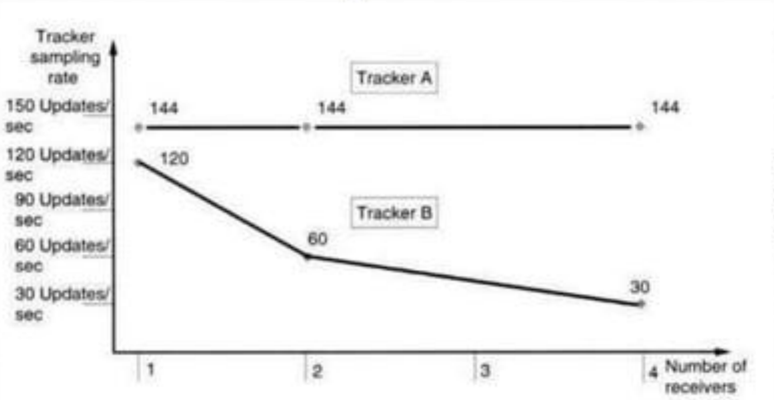


Fig. 2.4 Tracker update rate versus number of tracked objects.

- Tracker A uses dedicated electronics for each tracked object (sensor), such that its update rate is independent of the number of tracked objects.

- By contrast, tracker B has only one electronic interface, which cycles between multiple tracked objects. Its update rate is reduced by 50% when two objects are tracked and by 75% when the electronics cycles among four measuring points (3D objects).

- Choosing between the two alternatives depends on the requirements of the VR application.

Types of Trackers

1. **Mechanical Trackers**
2. **Magnetic Trackers**
3. **Ultrasonic Trackers**
4. **Optical Trackers**
5. **Hybrid Inertial Trackers**

2.1.4 Ultrasonic Trackers

- Definition: **A ultrasound tracker is a noncontact position measurement device that uses an ultrasonic signal produced by a stationary transmitter to determine the real time position of a moving receiver element.**

- Ultrasound trackers have **three components**: a **transmitter**, a **receiver**, and an **electronic unit**.

- A transmitter is a set of three ultrasonic speakers mounted about 30 cm from each other on a rigid and fixed triangular frame.

- Similarly, receiver is also a set of three microphones mounted on a smaller rigid triangular frame. This triangular frame is placed at the top of the head mounted display, as illustrated in Figure 2.14.

2.1.4 Ultrasonic Trackers

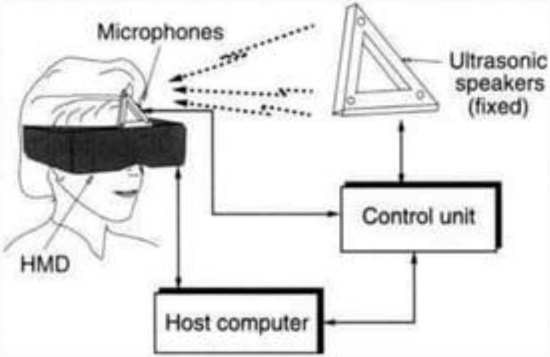


Fig. 2.14 Logitech ultrasound head tracker. From Burdea and Coiffet [1993]. © Editions Hermes. Reprinted by permission.

2.1.4 Ultrasonic Trackers

- Alternatively the microphones may be part of 3D mice, stereo glasses (discussed in the next chapter), or other interface devices.

- Due to their simplicity, ultrasound trackers represent a cheaper alternative to the magnetic trackers.

- The speed of sound in air changes for room temperature based on the law [Sheingold, 1981] $c = (167.6 + 0.6T_k)$ (2.3) where c is the speed of sound in m/sec and Tk is the air temperature in degrees Kelvin.

- **For a given temperature the speed of sound is known** and **can be used to measure distances** based on time of flight. The ultrasound tracker measurements are based on triangulation.

2.1.4 Ultrasonic Trackers

- Each speaker is activated in cycle and the three distances from it to the three microphones in the receiver are calculated.
- A total of nine distances is measured in order to determine the position and orientation of the plane that contains the three microphones.
- The **control unit CPU samples the microphones, converts their readings into position and orientation based on calibration constants, then transmits the data to the host computer for graphics scene rendering.**
- The update rate of ultrasound trackers is about 50 datasets/sec, which is less than half that of modern magnetic trackers.
- When several parts of the body (such as head and hands) have to be tracked, it is possible to use time multiplexing of up to four receivers with one transmitter.
- The drawback in this case is a further increase in simulation latency, since time multiplexing reduces the tracker update rate even more.

2.1.4 Ultrasonic Trackers

- When four receivers are tracked simultaneously, the update rate drops to (only) 12 datasets/sec! Using a single transmitter with multiple receivers has the additional drawback of limiting the total volume where the user's head and hands have to be.
- The operating range of ultrasound trackers is dependent on the attenuation of the transmitter signal due to molecular air absorption.
- A typical range might be 1.52 m (5 ft) from the ultrasound transmitter, but this is reduced significantly by the relative humidity of the air.
- A direct line of sight is required between the transmitter and the receiver of an ultrasound tracker, this is another significant drawback
- If some object obstructs the line of sight between an ultrasound transmitter and receiver or the user's head is turned away, the tracker signal is lost. The signal is also corrupted by background noise in the room as well as other ultrasound sources (such as the ones used in building security).

2.1.4 Ultrasonic Trackers

- **Certain applications may require a larger user motion volume than is allowed by a single transmitter**.
- The solution is to spatially multiplex several transmitters with a single receiver [Sowizral and Barnes, 1993]. **The transmitters have to be placed such that their conic tracking volumes overlap** (as illustrated in Fig. 2.15).

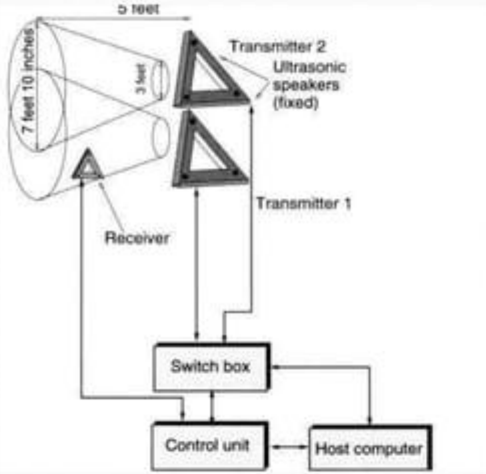


Fig. 2.15 Ultrasound tracking over large distances. Adapted from Sowizral and Barnes [1993]. © 1993 IEEE. Reprinted by permission

2.1.4 Ultrasonic Trackers

- In order to avoid mutual interference, it is necessary to turn on only one transmitter at a time. Thus the host computer has to determine where the receiver is and keep the corresponding transmitter on until the neighboring transmitter takes over, and so on.

- Rather than have several control boxes (one for each transmitter), it is more economical to interpose a switch box controlled by the computer. The analog switches in the box are normally closed on transmitter 1 and commute to transmitter 2 only when energized by the computer.

- This scheme can be extended to multiple transmitters.

- The computer activates the box based on predictive control, that is, determining the receiver position, velocity, and acceleration.

2.1.5 Optical Trackers

- **Definition:** An optical tracker is a noncontact position measurement device that uses optical sensing to determine the real time position/orientation of an object.

- Similar to ultrasonic trackers, optical trackers work through triangulation, require direct line of sight, and are immune to metal interference.

- Optical trackers, however, offer significant advantages over ultrasonic counterparts. **Their update rates are much higher and their latency smaller than those of ultrasonic trackers** because light (whether visible or infrared) travels much faster than sound. They are also capable of (much) larger work envelopes, which is increasingly important in modem VR systems.

- If the tracker sensing component (charge-coupled device [CCD] camera, photodiode, or other photo sensor) is fixed and some light beacons are placed on the user, the tracker is said to be **outside-looking-in**, as illustrated in Figure 2.16a [Welch et al., 2001].

- Position measurements are done directly, and orientation is inferred from the position data. Tracking sensitivity is degraded as the distance decreases between the beacons on the user's body and the distance increases between the user and the camera.

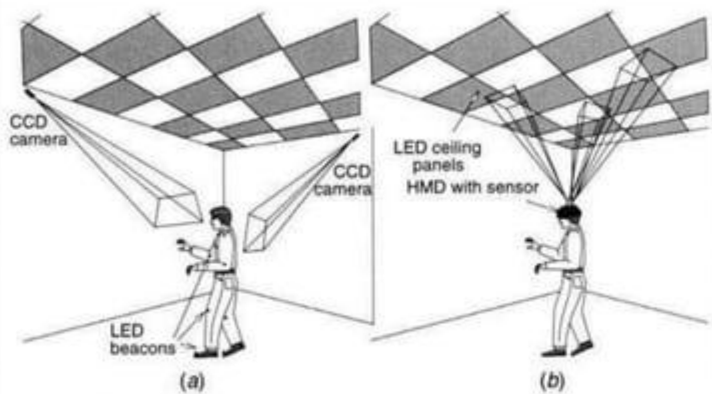
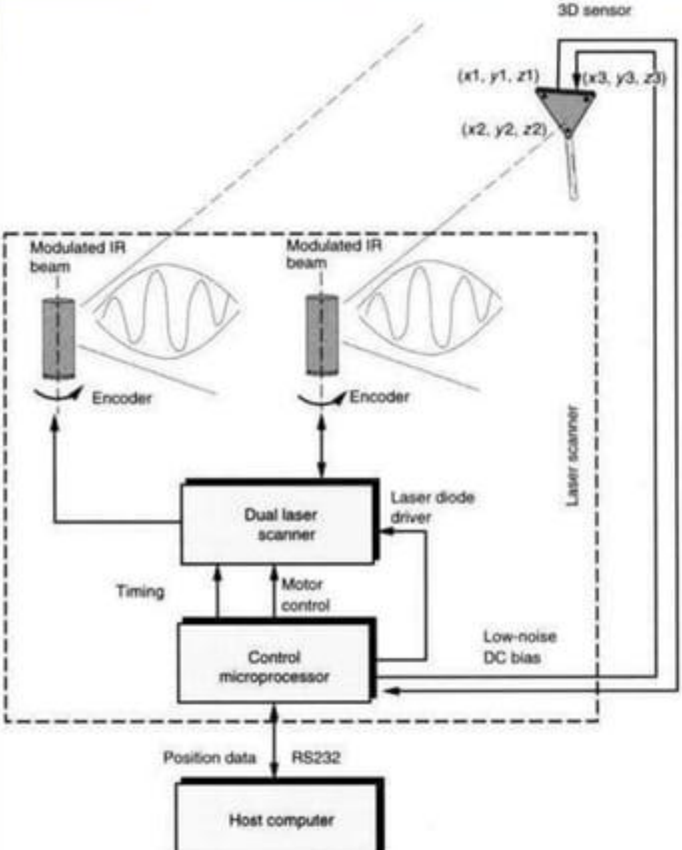


Fig. 2.16 Optical tracker arrangement: (a) **outside-looking-in**; (b) **inside-looking out.**
Adapted from Welch *et al. [2001].* © *2001 Massachusetts Institute of* Technology. Reprinted by permission.

- By contrast, an inside looking- out optical tracker has the camera(s) attached to the tracked object or user, as shown in Figure 2.16b.
- Traditionally, optical trackers have been outside-looking-in, and used primarily in motion capture for animation creation and biomechanics rather than for VR.
- **An inside-looking-out optical tracker system designed for use primarily in VR is the laser BIRD** produced by Ascension Technology Co. [Ascension, 2001a].
- As illustrated in Figure 2.17, the **tracker consists of a fixed laser scanner with dual rotary beams** and a mobile triangular sensing element that can be attached to the tracked object.
- **The laser scanners transmit two infrared (IR) modulated and offset light planes each, which intersect the sensing element**.



- An imbedded microprocessor in the scanner controls the timing of the laser scanners such that the scanning angles of the light planes detected as intersecting any of the sensors S1, S2, S3 are given by ai = wLti (2.4) where w is the scanner rotational speed.

- Fig. 2.17 Inside-looking-out laserBIRD optical tracker. Adapted from Hansen [1998]. © Ascension Technology Co. Reprinted by permission.

- The positions of the three sensors with regard to the scanner are computed by the microprocessor based on the known geometry of their triangular arrangement as well as the known offset of the two laser scanning heads and the angular offsets of the IR beams they produce.

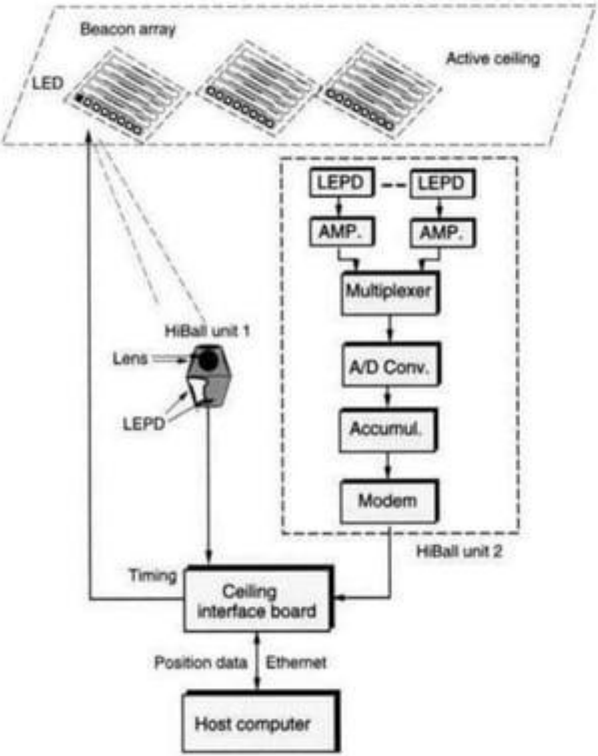
- Subsequently the position of the center of the triangular sensor is computed as the average of the triads (xl, yl, zl), (x2, y2, z2), and (x3, y3, z3) [Hansen, 1998].

- Complete 3D datasets are then transmitted to the host computer at a rate of 240 updates/sec over an RS232 line (115 kbaud).

- The operational range of the laser BIRD tracker is up to 2 m from the fixed laser scanner, with a positional accuracy of 1.0 mm root mean square (RMS) and an angular accuracy of 0.5° RMS.

- The tracker accuracy is comparable to, or better than, that of magnetic trackers, with better latency (less than 7 msec).

- Unlike other optical and hybrid trackers, this sensor is small (5.7 cm x 5.1 cm x 1.1 cm) and light (40 grams), making it comfortable to wear with HMDs.



Another example of inside-looking-out tracker is the HiBall 3000 produced by 3rdTech (Chapel Hill, NC) [Welch et al., 2001]. As illustrated in Figure 2.18,

Fig. 2.18 The HiBall 3000 optical tracker. Adapted from Welch *et al. [2001]*. © Massachusetts Institute of Technology. Reprinted by permission.

This optical tracking system consists of up to two HiBall units, LED beacon array(s), a ceiling-HiBall Interface, and a host computer.

The HiBall sensing unit incorporates IR-filtering lenses, lateral-effect photodiodes (LEPDs), and miniaturized electronic circuits.

There are six narrow-view (about 6°) lenses arranged in the six sectors of a hemisphere.

Their view is projected onto six corresponding LEPDs, such that one LEPD can receive views from several lenses.

The LEPD determines the x-y coordinates of a light spot that is the image of a pulsed LED on the beacon array.

The analog signal is amplified, multiplexed, and converted to a digital value, which is then sent to the ceiling interface board (CIB) using an on-board modem and wires.

The beacon arrays consist of 48 LEDs arranged in six parallel strips over an 8-ft2 surface modular with American false ceiling panels.

A number of beacon arrays can be added to increase the tracking envelope of the HiBall from 8 x 8 ft to 40 x 40 ft (12.2 x 12.2 m).

Each beacon array is connected to the CIB such that only one LED is pulsed at a given instant.

When that LED is imaged on several of the LEPDs it is possible to determine distance through triangulation because the geometries of the HiBall and of the beacon array being pulsed are known.

- The CIB improves processing speed and tracker accuracy by implementing a single-constraint-at-a-time algorithm, which uses Kalman fitering to compute the distance to an LED without attempting to do a complete 3D position measurement of the HiBall.

- These partial data are immediately combined with previous measurements to get the position and orientation of the HiBall, and the more the algorithm runs, the more accuracy and tolerance to ceiling imperfection is obtained.

- In the current configuration a single HiBall update rate is 2000 datasets/sec, which is an order of magnitude more that any other tracker discussed so far.

- When two HiBall sensing elements are daisy-chained, each delivers 1000 such 3D data sets every second, with an extremely small latency of less than 1 msec. The accuracy of this optical tracker is 0.5 mm RMS for position and 0.030 for orientation, which is maintained throughout the tracking surface.

- The weight of the optical sensor (about 300 grams or 11 oz) does raise an ergonomic concern, as do long wires that are still needed, since this version is not wireless.

- The research group at the University of North Carolina at Chapel Hill, which did the work that resulted in the HiBall, plans to convert the sensor to wireless operation and replace the six narrow-view lenses with fewer wider view ones. This should reduce the dimensions (and weight) of the sensing

2.1.6 Hybrid Inertial Trackers

- Definition: Inertial trackers are self-contained sensors that measure the rate of change in an object orientation.
- They may also measure the rate of change of an object translation velocity or acceleration, using solid-state accelerometers.
- The Modern inertial trackers are solid-state structures that works on micro electro mechanical systems **(MEMS) technology**.
- The rate of change in object orientation, or angular velocity, is measured **by Coriolis-type gyroscopes.**
- **Three such gyroscopes** are on mutually **orthogonal axes, measuring yaw, pitch, and roll angular velocities.**
- The orientation angle about the three orthogonal axes is then determined through **integration over time.**

2.1.6 Hybrid Inertial Trackers

- By knowing the tracked object orientation (from gyroscopic data) and subtracting the gravitational acceleration allows the computation of accelerations in world coordinates.

- The tracked object position is **finally obtained through double integration over time and knowledge of starting position** (calibration).

- Inertial trackers offer the **advantage of source less operation with theoretically unlimited range, no line-of-sight constraints, and very low jitter** (sensor noise).

- Therefore no **additional time-consuming filtering is needed, with beneficial effects on reducing latency.**

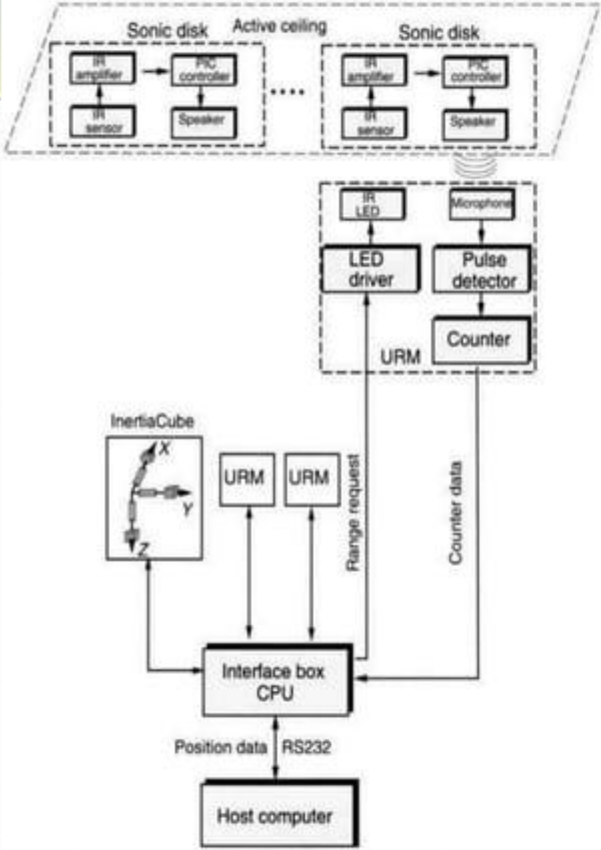
drawbacks

- Inertial trackers have a significant drawback, namely **rapidly accumulating errors, or drift.**
- Any gyroscope bias leads to an orientation error that increases proportionally with time due to integration.
- And Accelerometer bias in turn induces an error that increases with the square of time.
- The problem occurs by the use of gyroscope (drifted) data in computing position.
- Therefore Foxlin [2002] estimated that position drift can grow to as much as 40mm in 2 sec for commercial-grade inertial sensors.
- The much more expensive strategic-grade inertial trackers also have the same drift after 200 sec, a time interval.
- The answer to the drift problem is to use the data from other types of trackers to periodically reset the output of inertial ones.

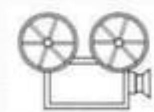
Hybrid tracker

- Definition: A hybrid tracker is a system that utilizes two or more position measurement technologies to track objects better than any single technology would allow.
- When only orientation data are needed, such as for low-cost HMDs, then one solution is to add solid-state magnetometers aligned with the three gyroscopes.
- Data from the three magnetometers can be used to determine the local magnetic North, which is unchanged regardless of the user's head orientation.
- This compensates the drift in the yaw (or azimuth) measurement.
- The 3D Bird has an accuracy of 4°, an update rate of 160 datasets/sec, and a latency of 15 msec. The InterTrax2 has an accuracy of 5°, an update rate of 256 datasets/sec, and a latency of 4 msec.
- Both trackers do processing on-board, such that a single RS232 line is needed to connect to the host computer.
- Any disturbance of Earth's local DC magnetic field (such as a large metal) will impact the performance because it affects the reading on the magnetometers used to compensate drift.

onic-inertial tracker



- Inertial trackers that provide both orientation and position data need additional means to compensate for drift. An example is the InterSense IS-900 ultrasonic-inertial tracker [Foxlin et al., 1998], illustrated in Figure 2.19.
- Fig. 2.19 The InterSense Inc. IS-900 block diagram. Adapted from Foxlin *et al.* [1998]. © 1998 ACM Inc. Reprinted by permission.



Inter Sense IS-900 ultrasonic-inertial tracker

- In order to limit the drift due to misalignment, all gyroscopes and accelerometers are machined out of a single cube, called the Inertia Cube.
- The Inertia Cube is combined with a number of ultrasonic range finder modules (URMs) to form a tracking station.
- The URM contains an infrared LED, omnidirectional microphone, and related electronics (time-ofarrival detector and counter).
- The counter is started when the IR LED sends a signal to an array of ceiling-mounted ultrasonic speakers, or sonic disks.
- Each sonic disk is self-contained (battery-operated) and has an IR sensor and electronics to decode the IR LED signal.
- If a particular sonic disk-IR code is detected, then that sonic disk emits a 40-kHz ultrasound.
- The measured URM counter data are sent to an interface electronic unit, where they are used to determine range.
- The interface CPU merges (fuses) range with data coming from the Inertia Cube to obtain reliable 3D position/orientation.

- The way the ultrasonic range data are fused with the inertial gyroscopic and accelerometer data is illustrated in Figure 2.20 [Foxlin et al., 1998].
- The tracking algorithm first uses integration, and in the case of accelerometers, double integration, to get orientation and position data to the host computer.
- This direct output insures overall low latency of the hybrid tracker.
- The output data are fed back into an estimation Kalman filter (EKF), where they are compared with data from the ultrasonic range measurement, in the same singleconstraint- at-a-time (SCAAT) fashion as in the HiBall.
- The EKF then estimates the amount of drift and resets the integration processes.
- Range data are rejected if background noise corrupts the URM data (premature counter stop).
- Using this hybrid tracking approach, the IS-900 Large Area Tracker (LAT) model can track over a surface from 6 x 6 m2 to 900 m2 with an accuracy of 4 mm and 0.2°.

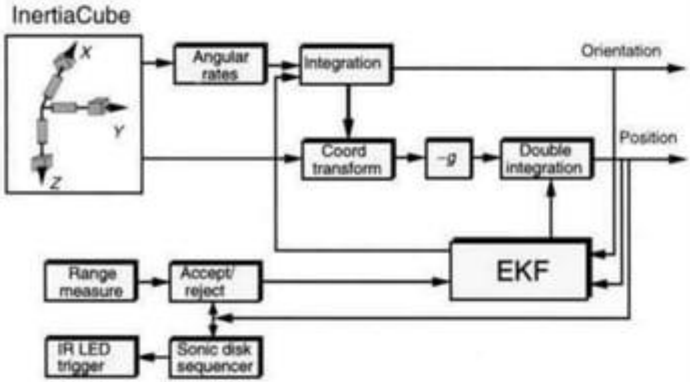


Fig. 2.20 The InterSense Inc. IS-900 software block diagram. Adapted from Foxlin *et al*. [1998]. © 1998 ACM Inc. Reprinted by permission.

update rate depends on how many trackers are used simultaneously, dropping from 180 datasets/sec for two tracking stations to 90 datasets/se c when four trackers are used simultaneously.

This drop in update rates is due to the waiting time imposed by ultrasonic range tracking used in drift correction and tracker initialization.

Data are sent to the host computer over an RS232 line with 4-10 msec latency [InterSense, 2000b].

Thank You