IVR: Sensing Self-Motion

26/02/2015

informatics

Overview

- Proprioception
- Sensors for self-sensing
  - in biological systems
    - proprioception
    - vestibular system
  - in robotic systems
    - velocity and acceleration sensing
    - force sensing
    - position sensing
- Vision as proprioception

Why robots need self-sensing

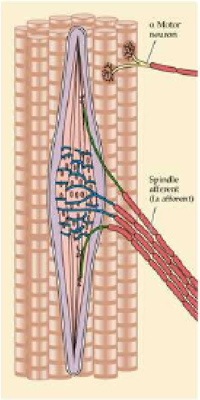
- For a robot to act successfully in the real world it needs to be able to perceive the world and its relation to the world.
  - The state of the robot is not entirely up to the robot itself, but also reflects external events. Thus, information about the "body" is an important source of information about the world.
  - Another use of proprioceptive information is stabilisation and smoothing of planned movements against perturbations.
- In particular, to control its own actions, the robot needs information about the position and movement of its body and parts
- Our body contains at least as many sensors for our own movement as it does for signals from the world.

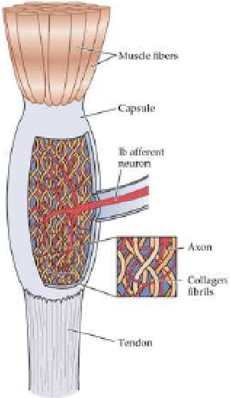
Interoception in humans

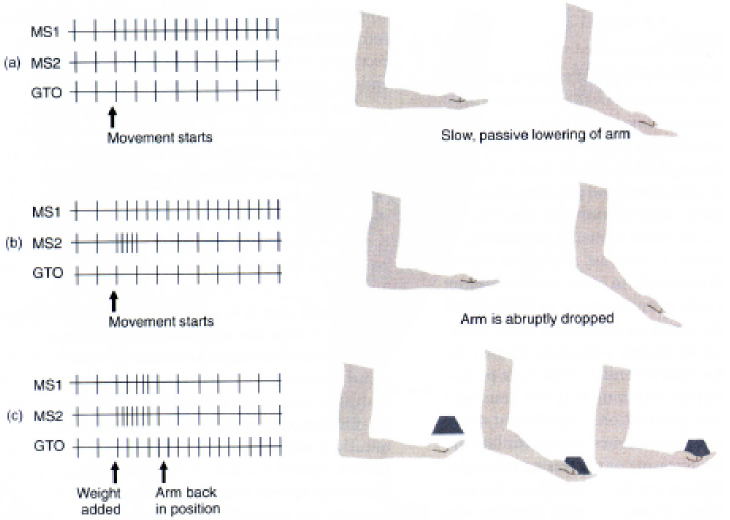
- Mechanoreceptors: Occur often in two types: deviations to below and above standard
  - in the lungs sense stretch and contribute to the control of the respiration rate
  - in brain arteries are involved in blood pressure regulation (baroreceptors)
  - in the gastrointestinal tract sense gas distension
  - in the bladder and rectum report fullness
  - various types of exteroceptive mechanoreceptors
- Nociception (sensing pain; different from but intertwined with sensing of pressure and touch)
- Thermoception in the brain (hypothalamus) regulating body temperature
- Chemoreceptors measure carbon dioxide and oxygen levels in the brain, presences of hormons, salt, sugar etc. in the blood
- Chronoception?

Proprioception: Detecting our own movements

- To control our limbs we need feedback: Kinesthesia
- Muscle spindles
  - where: length
  - how fast: rate of stretch
- Golgi tendon organ
  - how hard: force
- Pressure sensors in skin (e.g. finger movements)
- Pinocchio illusion

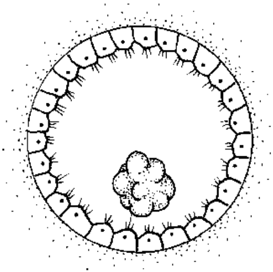





MS1
(a) MS2
GTO
Movement starts
Slow, passive lowering of arm
MS1
(b) MS2
GTO
Movement starts
Arm is abruptly dropped
MS1
(c) MS2
GTO
Weight added
Arm back in position

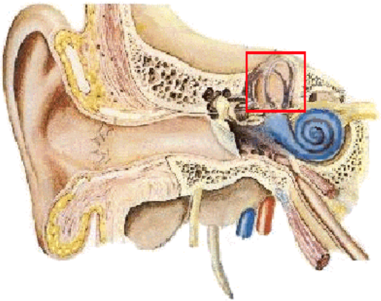
The vestibular system

- Detection of whole-body motion: Vestibular system based on statocysts (or otolithic organ in vertebrates)
- Statoliths (otoliths) are calcium nodules affected by gravity (or inertia during motion) cause deflection of hair cells that activate neurons



Note that sometimes the term *proprioception* is reserved for muscle and joint sensors. The integration of this and the vestibular inputs is then called *kinesthetic sense*.

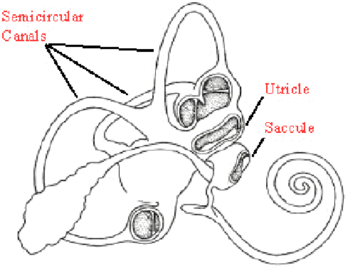
Self-sensing in animals



- Semicircular canals detect rotary acceleration in three orthogonal axes

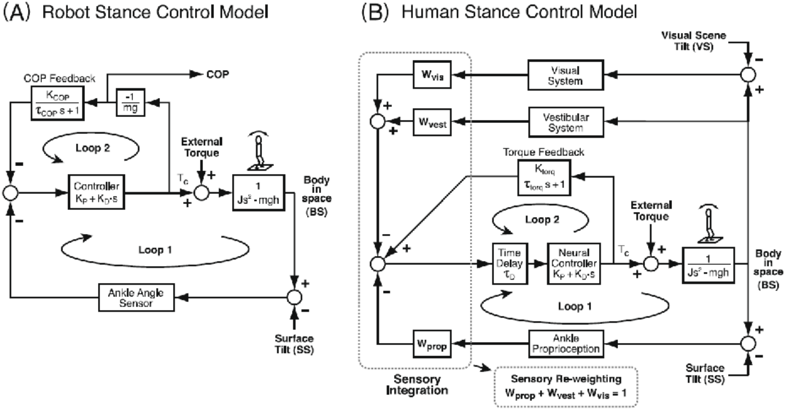
Vestibular System

- Linear acceleration detected by Utricle (horizontal) and Saccule (vertical) based on otoliths
- Dysfunction causes vertigo



Used e.g. in the fast vestibular-ocular reflex for eye stabilisation

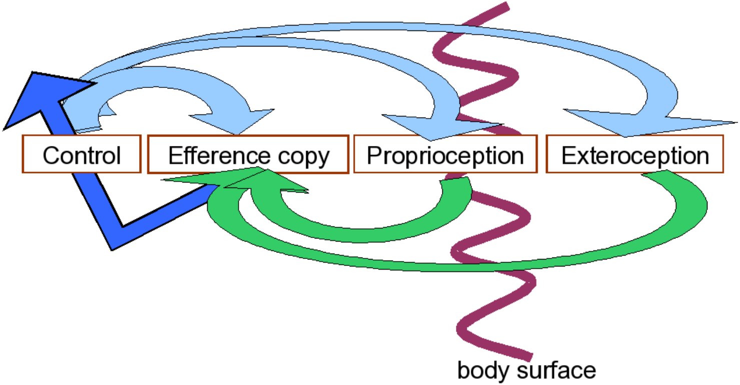
Outlook to control theory



Robert J. Peterka (2009) Comparison of human and humanoid robot control of upright stance. Journal of Physiology – Paris 103, 149–158

COP: center of pressure; optic flow and gyroscopes are used too in robot stance control

Using proprioceptive information: Efference copy



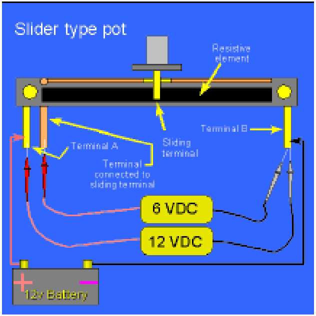
Efference copy

- A forward model predicting the effects of own actions
- Distinction between self and non-self (Tickling!)
- Anticipating the self-movement-induced changes of the electric sensations in weakly electric fish
- Grip force changes without time lag for known loads
- Efference copy is quite unreliable, not clearly localisable in the brain, and has low resolution:
- Gaze stabilisation
    - Visual input (highest priority)
    - self-sensing head and body movement by vestibular system
    - efference copy at active movements

For a robot:

Need to sense motor/joint positions with e.g.:

- Potentiometer (current measures position)
- Optical encoder (counts axis turning)
- Servo motor (with position feedback)

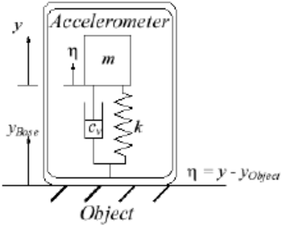


Proprioception for a robot

- Velocity by position change over time or other direct measurement: Tachometer, e.g. using principle of dc motor in reverse: voltage output proportional to rotation speed
- Acceleration: could use velocity over time, but more commonly, sense movement or force created when known mass accelerates, i.e. similar to statocyst
- Common uses of proprioceptive measurements are for battery monitoring, current sensing, and heat monitoring.
- The robot measures a signal originating from within using proprioseptive sensors. Responsible for monitoring self maintenance and controlling internal status. Often same modality as contact sensors (in contrast to distance sensors)

Kinestetics for a robot

Accelerometer:
measures displacement of weight due to inertia



Gyroscope:
uses conservation of angular momentum

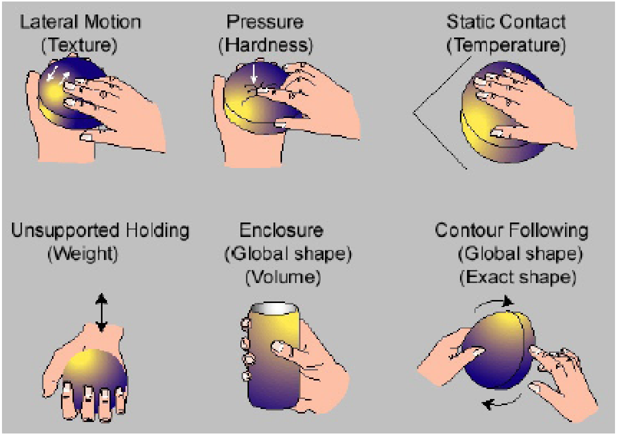
- There are many alternative forms of these devices, allowing high accuracy and miniaturisation (e.g. ceramic piezo gyros, MEMSs)

Inertial Navigation System (INS)

- Based on an Inertial Measurement Unit (IMU)
- Three accelerometers for linear axes
- Three gyroscopes for rotational axes (or to stabilise platform for accelerometers)
- By integrating over time can track exact spatial position
- Viable in real time with fast computers
- But potential for cumulative error

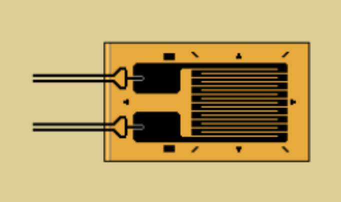
Haptics as exproprioception

Combining muscle & touch sense



Force sensing in a robot

- Spring and potentiometer
- Resistance change with deformation: Strain gauge →
- Piezoelectric – charge created by deformation of quartz crystal (n.b. this is transient)
- Nanowire active matrix (Nature Materials 2010) for artificial skin
- BioTac sensor (USC, 2012) →



More sensors for a robot:

Various other sensors may be used to measure the robot's position and movement, e.g.:

- Tilt sensors
- Shaft Encoders
- Compass
- Global Positioning System (GPS)
- May use external measures e.g. camera tracking of limb or robot position

Some issues for sensors

- What range, resolution and accuracy are required? How easy to calibrate?
- What speed (i.e. what delay is acceptable) and what frequency of sampling?
- How many sensors? Positioned where?
- Is information used locally or centrally?
- Does it need to be combined? How?
- Computational complexity

Using sense data

- Similar issues as with other sensors: Noise tolerance, reliability, context dependence
- Bayesian approaches:
  - testing hypotheses
  - combination of proprioception and exteroception
  - sensor fusion
- Evolutionary robotics: Adjust configuration of sensors

Proprioceptive control in BigDog

Boston Dynamics

- Proprioceptive sensors: linear pots, load cells, current sensors (4 of each per leg = 48)
- Homeostatic sensors: temperature sensors, sensors for oil flow, oil pressure, engine rpm, battery voltage
- Exteroceptive: gyro, 3 stereo vision systems, 1 LIDAR

Total: 69, most of which relate to the state of the robot

Marko B. Popovic (2013) Biomechanics and Robotics.

Odometry: Using self-sensing to estimate position

- Odometry is an internal mechanism that estimates the robot's position relative to a starting point by adding up the distance travelled (from gr. *hodos*, meaning "travel", "journey")
- Know present position (x, y, ϕ)
- Know how much wheels rotate or count steps
- New position $=$ old position $+$ change of position based on commanded motion
- Computationally simple
- Dead-reckoning is similarly based on the measurement of speed perhaps including a heading sensor (compass)

Odometry: Discussion

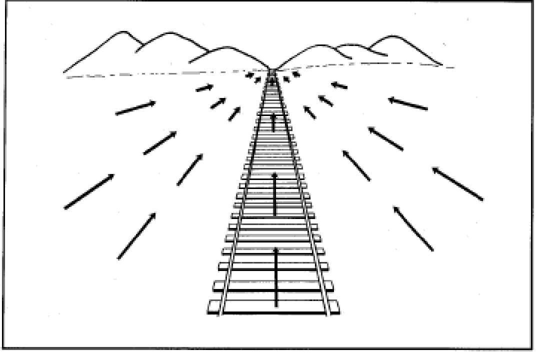
- Less reliable when done based on motor commands: Motors may be inaccurate and low-level controllers may compromise the high-level control command
- Use proprioception (shaft encoders) instead of an “efference copy”
- Calibration reduces systematic errors
- Prone to “random” errors: wheel slip, surface roughness, wall contacts, noise, imprecise measurement; errors tend to accumulate
- Remaining in sync with the environment: Some feature tracking needed. Combine with landmark/beacon-based navigation
- The angular component of the position is particularly critical: a compass may help
- Movement model tends to be less precise for curved trajectories: Constrain behaviour to a few types (“straight” and “turn in place”) to make calibration easier.

Vision as proprioception?

- An important function of vision is to direct control of motor actions
- Experiment: Standing on one leg with eyes closed ...
- Derive proprioceptive information from changes in visual input

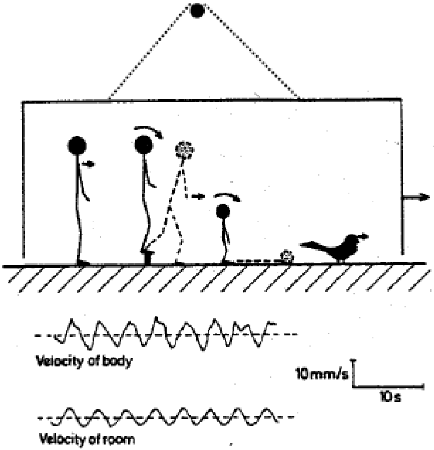
Optical flow

FIGURE 11.7



The optic flow field for a person sitting on the roof of a train, facing backwards.

V. Bruce, P. R. Green, M. A. Georgeson (2003) *Visual Perception: Physiology, Psychology, & Ecology*. Psychology Press.

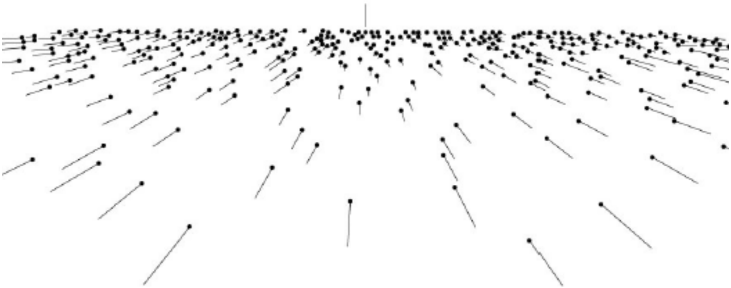


The ‘swinging room’ - Lee and Lishman (1974)

see also at youtube: Vision-Movement-Balance; A Study of Visual Kinaesthesis (1974)

Optical flow:

Heading = focus of expansion

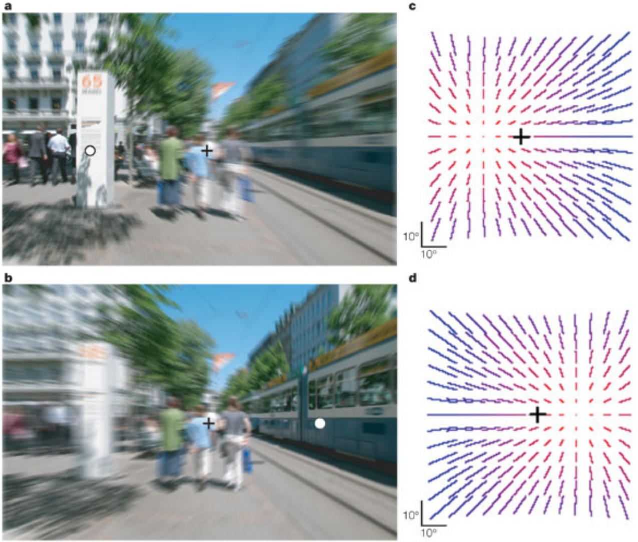


Homogeneity of optical flow gives usually good cue for self-motion

. . . provided that it can discount flow caused by eye movements

Optical flow:

Flow on retina = forward translation + eye rotation



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Optical flow:

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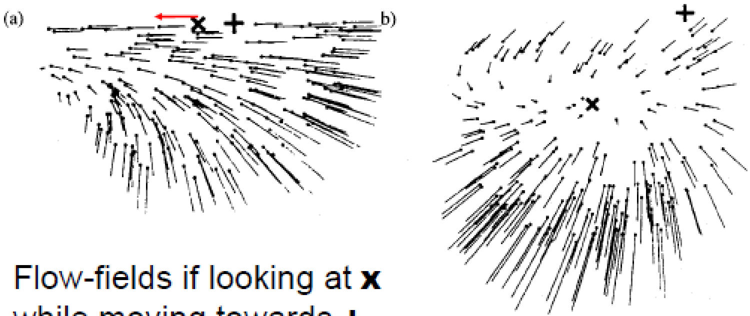
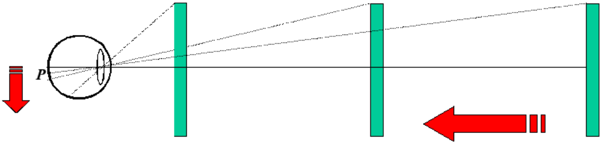


Flow-fields if looking at **x** while moving towards **+**
Bruce et al (op. cit) Fig 13.6

(left) Direction of motion differs from direction of gaze and gaze stabilizing eye movement reflexes are taken into account. (right) Direction of motion differs from direction of gaze and the observer tracks a moving object.

From optical flow to time of contact



P: distance of image from center of flow
Y: velocity of P on retina

X: distance of object from eye
V: velocity of approach

$$P/Y \approx X/V = \tau$$

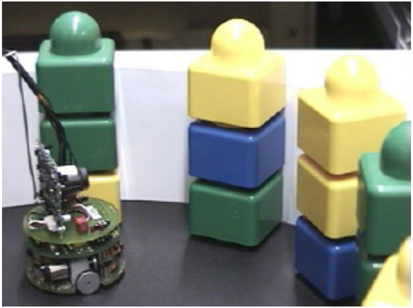
rate of image expansion ≈ time to contact

Lee (1980) suggested visual system can detect τ directly and use to avoid collisions e.g. by correct braking.

Expansion cues in robots

Using expansion as a cue to avoid collision is a common principle in animals, and has been used on robots

E.g. robot controller based on neural processing in locust – Blanchard et. al. (2000)



Summary

- Have discussed a variety of natural and artificial sensors for self motion
- Have hardly discussed how the transduced signal should be processed to use in control for a task
- Proprioceptive information needs to be continuously reconciled with exteroceptive information