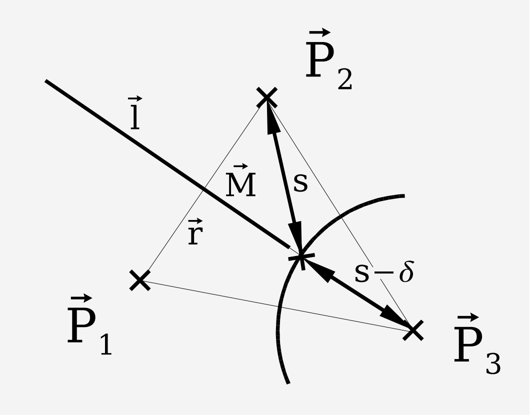
Exercise Sensor Networks - (till July 4, 2005)

Lecture 10: Applications for synchronization in sensor networks

Exercise 10.1: Signal propagation times

Three sensors detect an acoustic signal at times t1, t2 and t3. The positions of the nodes are denoted with P1, P2 and P3. Nodes 1 and 2 hear the signal at the same time but node 3 detects it d time units earlier (or later for d < 0). Where is the event producing the noise located for varying values of d?

Solution:



Analog to the proceeding in the lecture a perpendicular is drawn between nodes P1 and P2. All points on the perpendicular have the same distance to P1 and P2. That is why the two nodes hear the event at the same time.
In addition the signal is perceived d time units earlier at node 3. This means as a consequence that node 3 must be „d time units" nearer to the source. d time units correspond to dx300 meter.

$$\vec{x}_p = \vec{M} + p\,\vec{l} \qquad \delta = d \times 300\,\mathrm{m/s}$$

$$|x_p - P_1|^2 = |x_p - P_3|^2 - \delta^2$$

$$x_p^2 - 2x_pP_1 + P_1^2 = x_p^2 - 2x_pP_3 + P_3^2 - \delta^2$$

$$2x_pP_3 - 2x_pP_1 = P_3^2 - P_1^2 - \delta^2$$

$$2x_p(P_3 - P_1) = P_3^2 - P_1^2 - \delta^2$$

$$2(\vec{M} + p\,\vec{l})(P_3 - P_1) = P_3^2 - P_1^2 - \delta^2$$

$$p = \frac{P_3^2 - P_1^2 - \delta^2 - \left(2\vec{M}(P_3 - P_1)\right)}{2\,\vec{l}\,(P_3 - P_1)}$$

Exercise Sensor Networks

Lecture 10: Applications for synchronization in sensor networks

Exercise 10.2: Special cases of distance measurements

Only two nodes at the boundary of a sensor network hear the same event. Based on the different arrival times of the signal or in other words based on shorter or longer signal propagation times from the event to the nodes the direction of the event can be guess.

This direction or angle is not always precise as we have seen in the lecture (at least not when based on two nodes).

a) When can the direction of the incoming sound theoretically be determined precisely and why can the angle not always be determined without an error?

Solution:

If each node hears the event at the same time it must have the same distance from both nodes. The signal propagates into all direction with the same speed so it reaches each point on the shortest way. If the time from the even to the nodes is the same the direct line between the event and the nodes must have the same length. That is why the even must be located on the perpendicular (of the direct line between the nodes).

If the sound (imaging a spherical wave) arrived "parallel" or with 0° to the line between the nodes then the sound travels as long as possible between them. The longest journey between the nodes can only be achieved if the sound producing source is located on the line between the nodes.

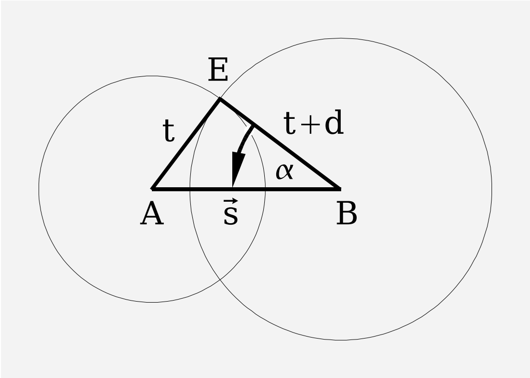
For all remaining cases in between 0° and 90° the event could be located on a slightly bend curve and not on a straight line. That is why a unique angle can not be determined. On other words: Many locations would lead to the same difference of perception times at the nodes.

Exercise Sensor Networks

Lecture 10: Applications for synchronization in sensor networks

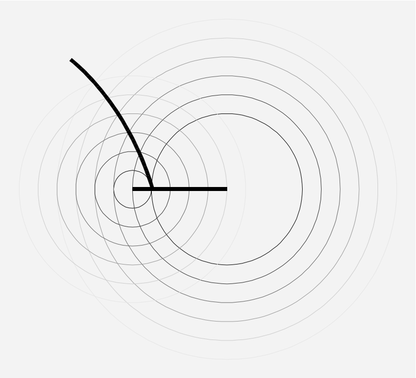
Exercise 10.2: Special cases of distance measurements

b) Two nodes detect an event, but one node detects is z time units later than its fellow. On what curve could the even be located for a given z?



Solution:

The time difference of z time units has to be transformed into a (spacial) distance d. Then the distance t around node A (see the upper right sketch) can be chosen arbitrarily. The event E must lay on the circle. But it must at the same time be t+d units away from B. So all three side of the triangle A, B, E are known and the angle alpha can be determined by the law of cosine:



$$\alpha = \operatorname{acos}\left(\frac{\vec{s}^2 + (t+d)^2 - t^2}{2(t+d)|\vec{s}|}\right) = \operatorname{acos}\left(\frac{\vec{s}^2 + d(2t+d)}{2|\vec{s}|(t+d)}\right)$$

Alpha is then used to rotate the line s (=A-B) by (-alpha). The length of the rotated line should of course by (t+d). If B is added the location of event E is obtained, but only for the particular t chosen in the beginning.

$$E(t) = B + \begin{pmatrix} \cos(-\alpha) & -\sin(-\alpha) \\ \sin(-\alpha) & \cos(-\alpha) \end{pmatrix} \frac{t+d}{|\vec{s}|} \vec{s}$$

Varying the parameter t results in a trace of intersecting points E(t) between the two circles. Note that the same curve can be mirror at AB and the points are still valid locations for E. In other words: Each location will yield the same perception by nodes A and B.

Exercise Sensor Networks

Lecture 10: Applications for synchronization in sensor networks

Exercise 10.2: Event localization inaccuracies

Optional: Try to simplify the curve more in order to obtain a closed expression. Then two curves of different node pairs could be intersected to find the actual position E. Unfortunately, the simplification stopped as shown below:

$$E=B+\begin{pmatrix} \cos\left(-\operatorname{acos}\left(\frac{|\vec{s}|+d(2t+d)}{2|\vec{s}|(t+d)}\right)\right) & -\sin\left(-\operatorname{acos}\left(\frac{|\vec{s}|+d(2t+d)}{2|\vec{s}|(t+d)}\right)\right) \\ \sin\left(-\operatorname{acos}\left(\frac{|\vec{s}|+d(2t+d)}{2|\vec{s}|(t+d)}\right)\right) & \cos\left(-\operatorname{acos}\left(\frac{|\vec{s}|+d(2t+d)}{2|\vec{s}|(t+d)}\right)\right) \end{pmatrix}\frac{t+d}{|\vec{s}|}\vec{s}$$

$$E=B+\begin{pmatrix} -\frac{|\vec{s}|+d(2t+d)}{2|\vec{s}|(t+d)} & -\sin\left(-\operatorname{acos}\left(\frac{|\vec{s}|+d(2t+d)}{2|\vec{s}|(t+d)}\right)\right) \\ \sin\left(-\operatorname{acos}\left(\frac{|\vec{s}|+d(2t+d)}{2|\vec{s}|(t+d)}\right)\right) & -\frac{|\vec{s}|+d(2t+d)}{2|\vec{s}|(t+d)} \end{pmatrix}\frac{t+d}{|\vec{s}|}\vec{s}$$

$$E=B+\begin{pmatrix} -\frac{|\vec{s}|+d(2t+d)}{2|\vec{s}|^2} & \frac{t+d}{|\vec{s}|}\sin\left(\operatorname{acos}\left(\frac{|\vec{s}|+d(2t+d)}{2|\vec{s}|(t+d)}\right)\right) \\ \frac{t+d}{|\vec{s}|}\sin\left(-\operatorname{acos}\left(\frac{|\vec{s}|+d(2t+d)}{2|\vec{s}|(t+d)}\right)\right) & -\frac{|\vec{s}|+d(2t+d)}{2|\vec{s}|^2} \end{pmatrix}\vec{s}$$

Exercise Sensor Networks

Lecture 10: Applications for synchronization in sensor networks

Exercise 10.2: Event localization inaccuracies

$$E=B+\begin{pmatrix} -\frac{|\vec{s}|+d(2t+d)}{2|\vec{s}|^2} & \frac{t+d}{|\vec{s}|}\sin\left(\operatorname{acos}\left(\frac{|\vec{s}|+d(2t+d)}{2|\vec{s}|(t+d)}\right)\right) \\ \frac{t+d}{|\vec{s}|}\sin\left(-\operatorname{acos}\left(\frac{|\vec{s}|+d(2t+d)}{2|\vec{s}|(t+d)}\right)\right) & -\frac{|\vec{s}|+d(2t+d)}{2|\vec{s}|^2} \end{pmatrix}\vec{s}$$

$$E=B+\begin{pmatrix} -\vec{s}.x\frac{|\vec{s}|+d(2t+d)}{2|\vec{s}|^2}+\vec{s}.y\frac{t+d}{|\vec{s}|}\sin\left(\operatorname{acos}\left(\frac{|\vec{s}|+d(2t+d)}{2|\vec{s}|(t+d)}\right)\right) \\ -\vec{s}.x\frac{t+d}{|\vec{s}|}\sin\left(\operatorname{acos}\left(\frac{|\vec{s}|+d(2t+d)}{2|\vec{s}|(t+d)}\right)\right)-\vec{s}.y\frac{|\vec{s}|+d(2t+d)}{2|\vec{s}|^2} \end{pmatrix}$$

... ?

Exercise Sensor Networks

Lecture 10: Applications for synchronization in sensor networks

Exercise 10.3: Requests to the Tiny Aggregation Service (TAG)

Sensor nodes are scattered over a large area of a mountain landscape. Every node can measure the following quantities:

light
temperature
altitude

The mean temperature should now be determined at the same level of altitude, whereas the altitude in only defined in intervals of 100 meters (in other words: it is quantized to buckets of 100 meters).

Example: 51 up to 149 meters are assigned to be 100 meter. The function round() is available which returns arithmetically rounded integer values.

Only the temperature in the shadow is of interest, so only those node should take part in the determination which measure less than 100 Lux.

The temperature sensors used for the nodes are cheap so many of them are defective. Fortunately, defective sensors exhibit a temperature of less than -200° Celsius. A group containing a defective sensor should be canceled entirely.

Finally, the sensor network should provide the requested data once an hour.

Find the SQL-like query according to the TAG-model.

Exercise Sensor Networks

Lecture 10: Applications for synchronization in sensor networks

Solution Exercise 10.3:

`SELECT ROUND(height/100), AVG(temperature)`	
`FROM sensors`	
`WHERE light < 1000`	Here filtering takes place beyond any groups.
`GROUP BY ROUND(altitude/100)`	Here grouping takes place based on contour lines.
`HAVING MIN(temperature) >= -200`	The whole group is canceled if a single instance shows a temperature of -200° or less
`EPOCHE DURATION 60m`	That is the time a query may take. If the time is too short, maybe not the whole network can contribute measurements.