Visual Gyroscope and Odometer for Pedestrian Indoor Navigation with a Smartphone

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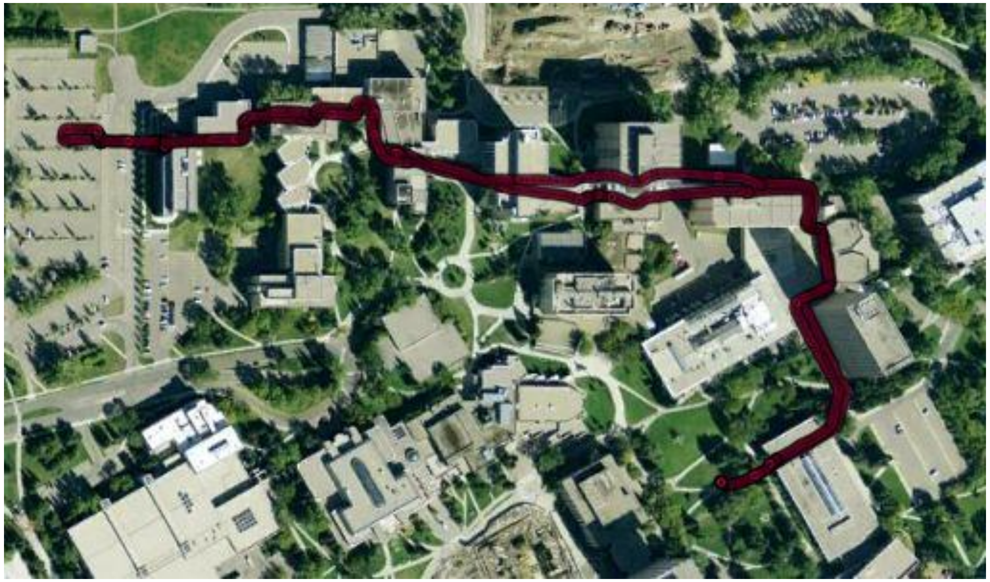


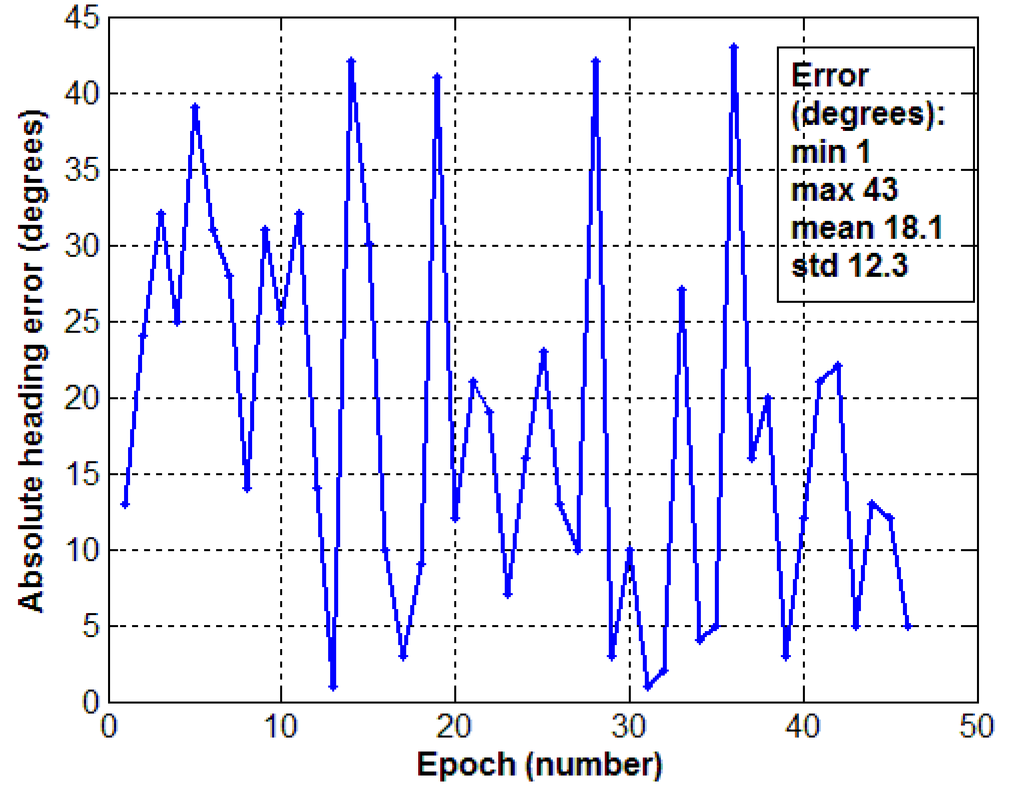
Overview

- Estimating the user attitude and translation by tracking features in consecutive images in the indoors
- Use of a camera carried by the user
- Attitude & translation integrated with other measurements => vision-aided navigation solution

Motivation

- Performance of GNSS is degraded indoors
- INS is feasible for aiding, problems especially with heading gyro drift and compass errors indoors
- Need for a system free from calibration and prior information of the environment and that is convenient for users

Heading errors with a Nokia 6710 smartphone compass in an office environment



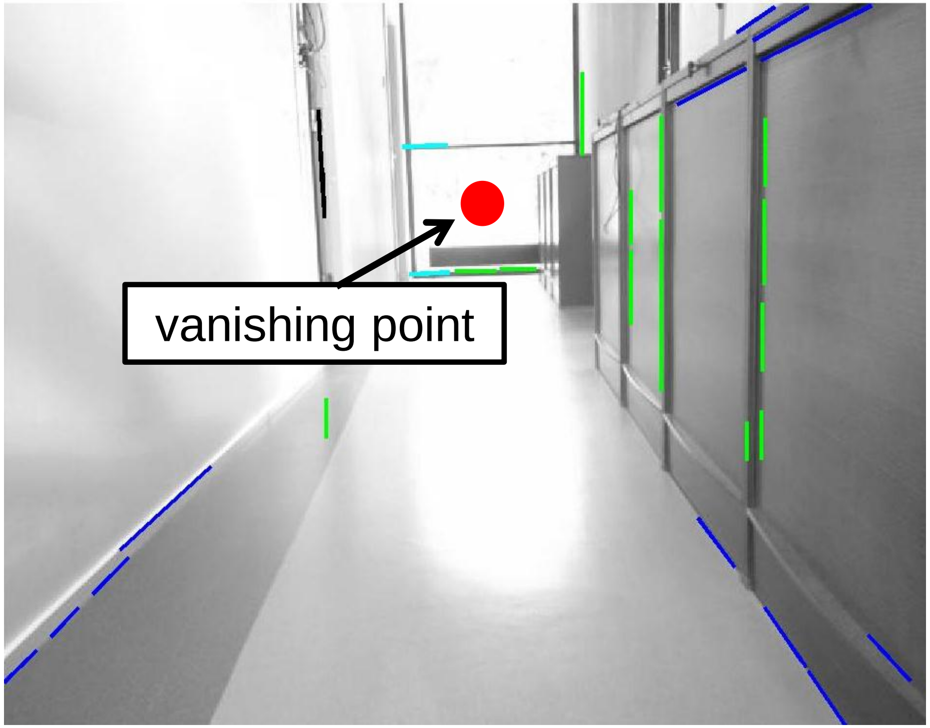
Visual gyroscope 1/3

- Human made environments are full of straight orthogonal lines
- Vanishing point is a point where **parallel lines** seem to **intersect** in an image due to perspective projection, mapping 3D environment into 2D features
- Lines in three orthogonal directions => three **vanishing points**
- Locations of vanishing points are related to camera intrinsic parameters (matrix **K**) and rotation of the camera (matrix **R**)

$$[\mathbf{v}_x \ \mathbf{v}_y \ \mathbf{v}_z] = \mathbf{KR}$$

Visual gyroscope 2/3

- Lines are classified based on their orientation
- Vanishing point $\mathbf{v}_z$ is the intersection point of lines in the direction of propagation (blue lines) and is found with a voting algorithm
- Reliability of the estimated vanishing point is measured based on the line geometry



Visual gyroscope 3/3

- Heading (ϴ) and tilt (φ) of the camera are obtained using the pixel coordinates of the $\mathbf{v}_z$ and **K** matrices

$$\mathbf{v}_z = \begin{bmatrix} f_x \sin\theta + u\cos\varphi\cos\theta \\ -f_y \sin\varphi\cos\theta + v\cos\varphi\cos\theta \\ \cos\varphi\cos\theta \end{bmatrix} \qquad \mathbf{K} = \begin{bmatrix} f_x & 0 & u \\ 0 & f_y & v \\ 0 & 0 & 1 \end{bmatrix}$$

$$\mathbf{R} = \begin{bmatrix} \cos\theta & 0 & \sin\theta \\ \sin\varphi\sin\theta & \cos\varphi & -\sin\varphi\cos\theta \\ -\cos\varphi\sin\theta & \sin\varphi & \cos\varphi\cos\theta \end{bmatrix}$$

$$[\mathbf{v}_x \ \mathbf{v}_y \ \mathbf{v}_z] = \mathbf{KR}$$

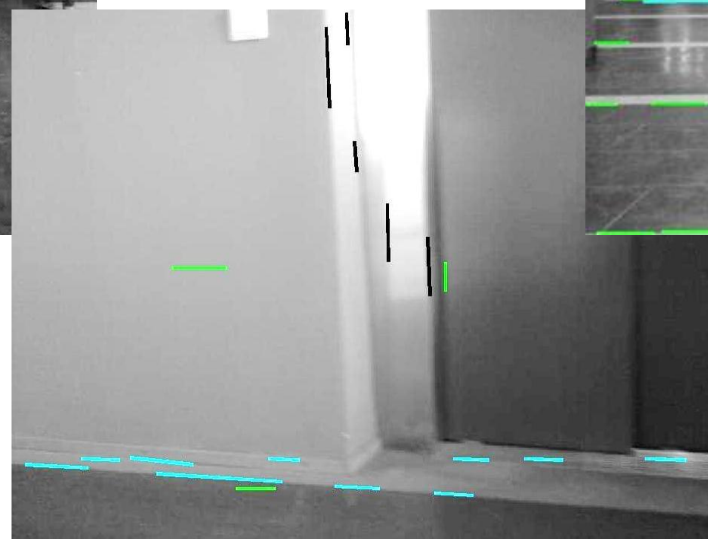
Strengths of visual gyroscope

- No prior information is needed for the evaluation of the heading change and tilt of the camera
- Dynamic objects are not significantly disturbing the process
- Is dependent only on lighting and geometry of the scene
- Sample statistics with 7555 images (1.2 s interval) and static camera (Nokia N8, image resolution 640 x 480):

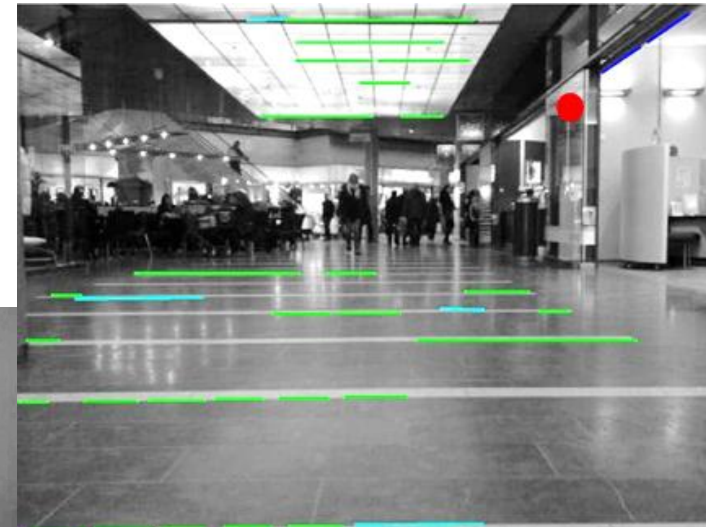
Statistics	**min error (degrees)**	**max error (degrees)**	**mean error (degrees)**	**Std of error (degrees)**
Heading change	0	18.4	0.8	0.59
Tilt	0	10.7	0.3	0.28

Challenges of visual gyroscope

Dark image:
vanishing point erroneous

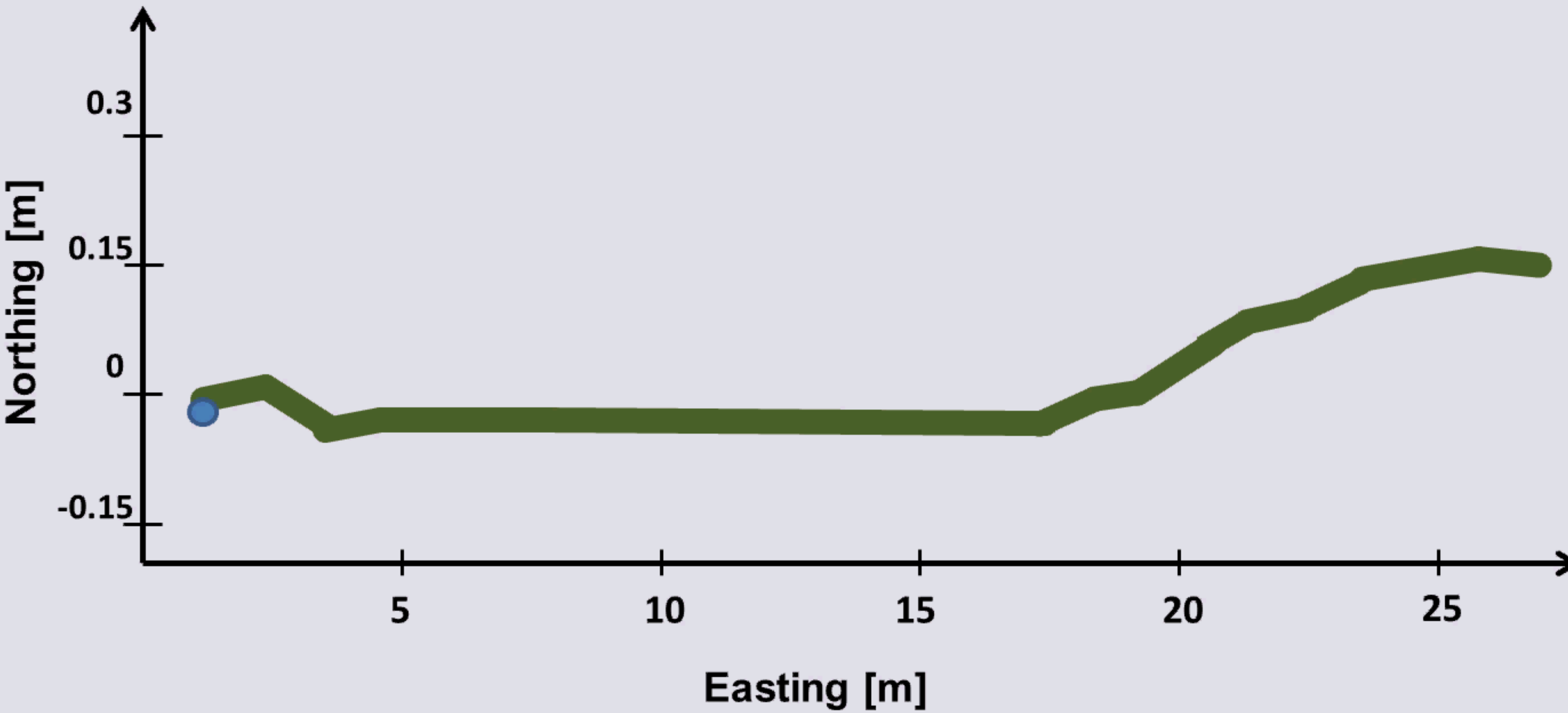


Turns – no lines in the direction of propagation:
no vanishing point



Scene geometry and parameter selection:
rate of success of finding correct vanishing point lower

Visual gyroscope's error detection discards measurements with poor line geometry and uses the subsequent good one



Reference heading, constant speed

Visual gyroscope heading, constant speed

Visual odometer 1/4

- Homography between image points **x** and **x**' of same world point defined with

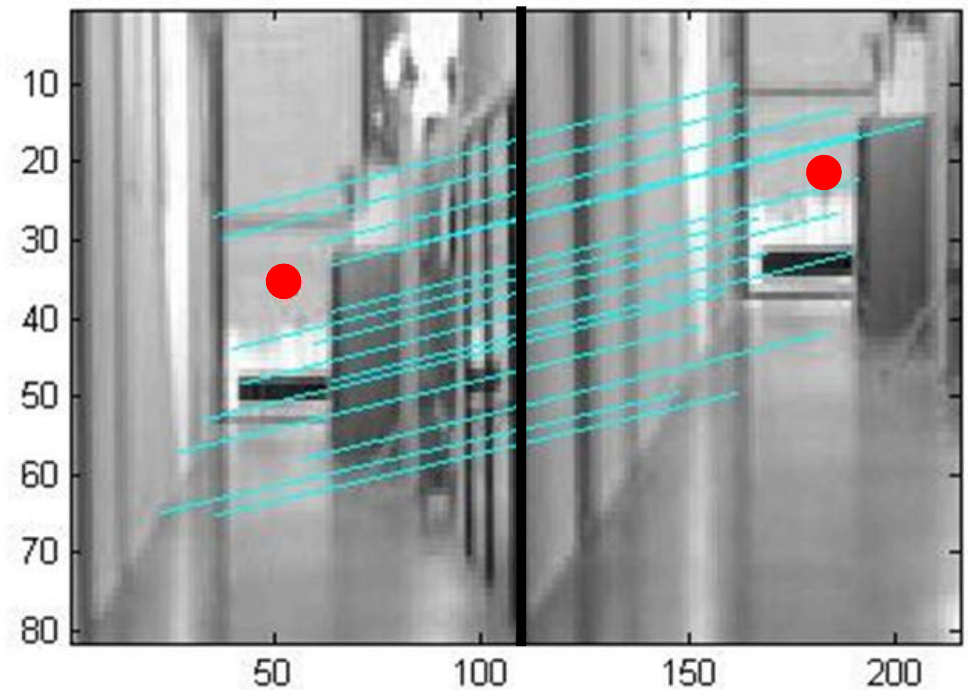
$$\mathbf{x}' = \mathbf{K}'\mathbf{R}\mathbf{K}^{-1}\mathbf{x} + \mathbf{K}'\mathbf{t}/Z$$

K and **K**' = calibration matrices

R rotation of the camera

t translation of the camera

Z distance to point



Matching of points with SIFT algorithm by D.G. Lowe, US Patent 6,711,293, filed 1999

- Problems:
  - the unknown *Z*
  - ambiguous scale

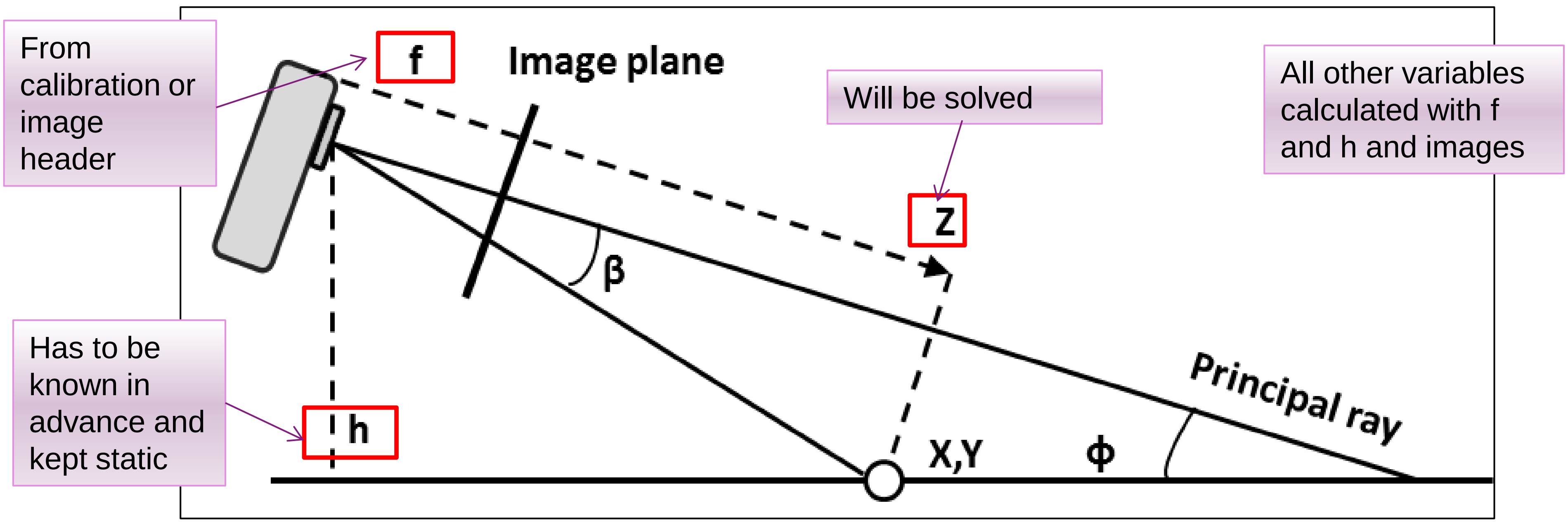
Visual odometer 2/4

- Some solutions in the literature for finding *Z*:
  - Stereo cameras => Known pose of the cameras give *Z* by triangulation : special equipment
  - Camera facing down with known height: might be problematic indoors due to uniform texture of the floor
  - Objects with known size: needs a priori preparation and is restricted to one area

Santos et al (2009). An analysis of navigation algorithms for smartphones using J2ME. *MOBILWARE*.

Visual odometer 3/4

- Calculating Z with special configuration of the camera
  - Campbell et al. 2005 for robots => tilt evaluated a priori, motion restricted, optical flow for outdoor environment
  - Ruotsalainen 2012 for pedestrians using a smartphone indoors / outdoors => tilt (ϕ) and heading with vanishing point, translation with image homography, camera may move quite freely



Visual odometer 4/4

- Matching points in consecutive images: SIFT[1]
- Only few features in indoor environment => uncertain matches must be accepted => wrong matches discarded
- Points have to lie on floor => lines used for calculating vanishing points normally found from the floor => points close to the lines used

1. SIFT patented by D.G. Lowe, US Patent 6,711,293, filed 1999

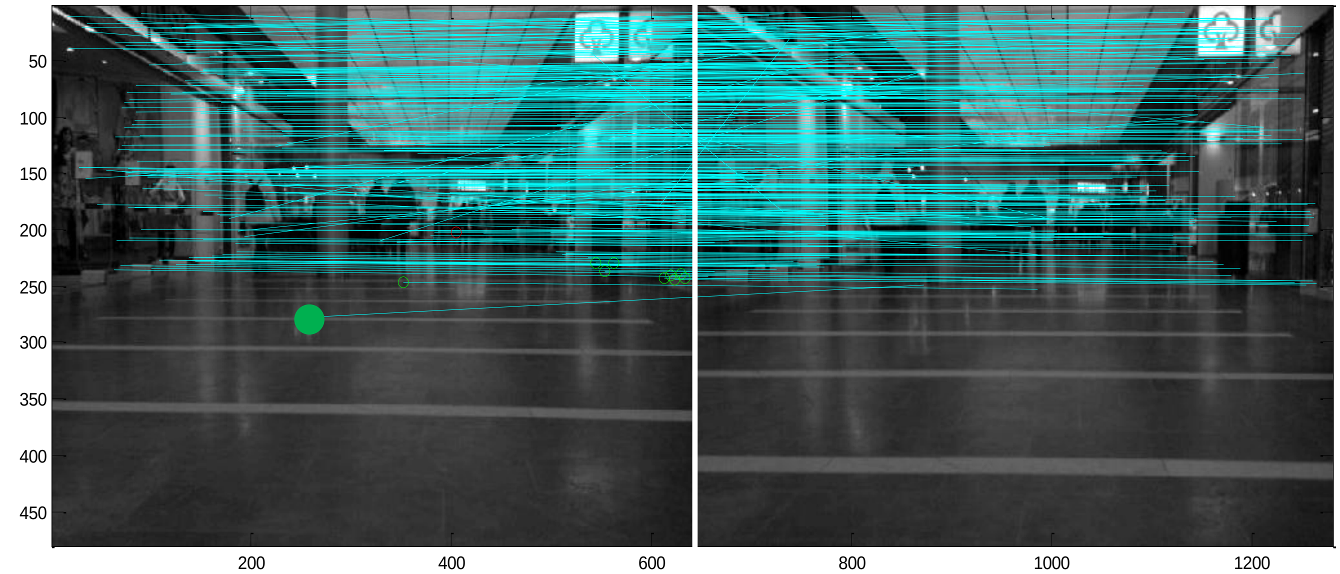
Strengths of visual odometer

- Rotation of the camera is obtained with vanishing points, the calibration matrix is known and the height of the camera is static to some extent => only translation in x and z- axes is unknown => this decreases the number of matched points needed for calculation
- Speed measurements require information only of the height of the camera
- Performance of the visual odometer tested in an office corridor – errors in relation to the Novatel SPAN GPS /INS reference

Statistics Speed	min error (m/s)	max error (m/s)	mean error (m/s)	std of error (m/s)
	0	2.3	0.3	0.3

Challenges of visual odometer

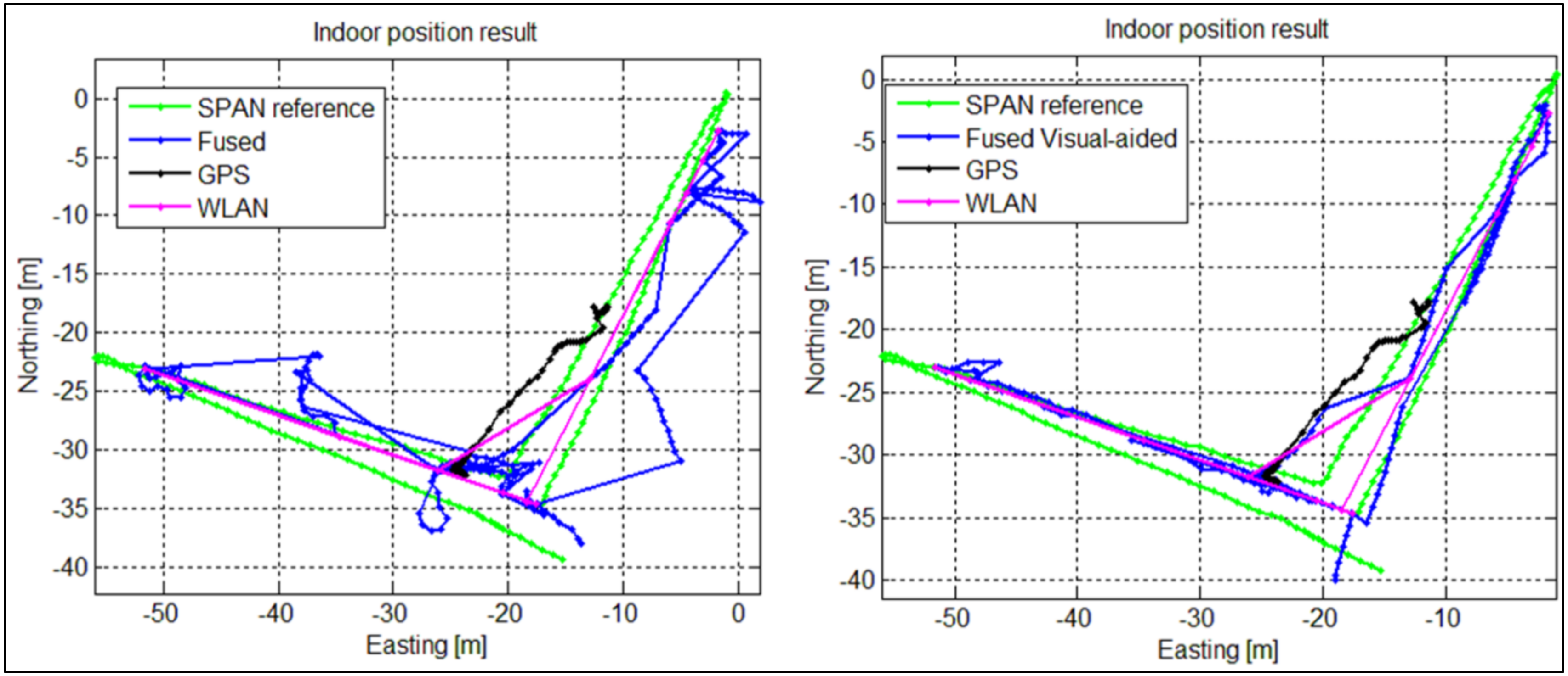
- Points have to lie close to the camera
- Indoor environments often poor with features => problems finding even one matching point close to the camera
- Effect of vanishing point calculation errors => erroneous vanishing point decreases accuracy of measured speed



Experiments

- Fastrax IT500 GPS receiver
- Nokia 6710 mobile phone for WiFi
- Multi-sensor positioning device with
  3-axis accelerometer (VTI) and
  2-axis digital compass (Honeywell)
- Nokia N8 camera for visual-aiding

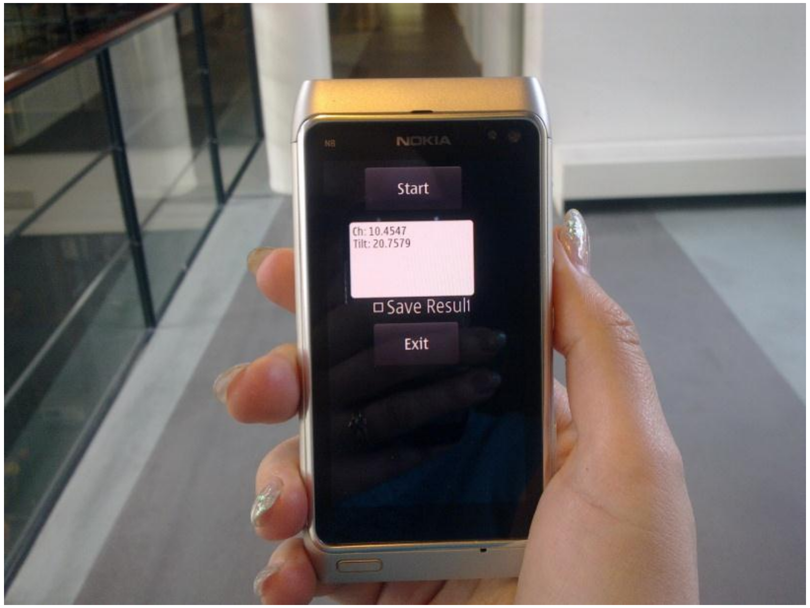
Visual-aided multi-sensor multi-network navigation solution



	min errors (m)	max errors (m)	mean errors (m)	std of errors (m)
Fused	0.9	23.4	6.7	5.1
Fused with visual aiding	0.9	19.7	5.3	3.7

Summary

- User heading and speed may be obtained using information from consecutive images
- Accuracy suitable for pedestrian navigation
- Improves integrated navigation solution



On-going and future work

- Tested in three other different environments
  - Mean error in speed is around 0.25 m/s in all test environments
  - Accuracy of cumulative distance is over 90% in all test environments
- Processing times of the visual gyroscope with Nokia N8
  - Taking a photo : 1.2 s
  - Edge detection (Canny) : 0.17 s, line detection (Hough lines) : 1.0 s
  - Vanishing point and heading & tilt calculations : 0.07 s
  - **Total 2.7 s**
- How does roll and change in camera height affect accuracy?

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