"From the wisdom of the ages to the challenges of modern world"

FIG WORKING WEEK 2015
17–21 MAY SOFIA BULGARIA

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FACULTY OF CIVIL ENGINEERING

Pedestrian Trajectory Determination in Indoor Environment

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Indoor navigation technologies

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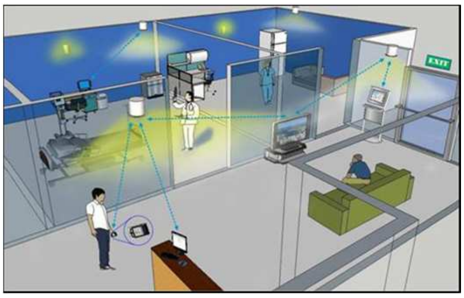
- Increasing need of the navigation systems in indoor environment (hospitals, rescue services, universities, shopping malls,...) – GNSS signal can´t be used, only outdoor
- **WiFi** - principle based on wireless network WLAN and received signal strength
- Radio Frequency
- Pseudolites
- Visual techniques
- Inertial navigation



Indoor navigation technologies

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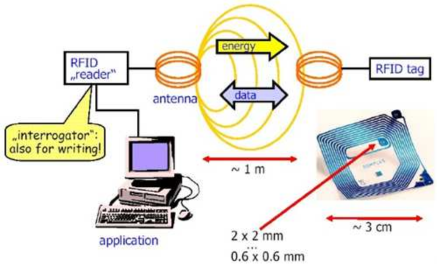
- Increasing need of the navigation systems in indoor environment (hospitals, rescue services, universities,...) – GNSS signal can´t be used
- WiFi
- **Radio Frequency** - electromagnetic communication between RF reader and tag
- Pseudolites
- Visual techniques
- Inertial navigation



Indoor navigation technologies

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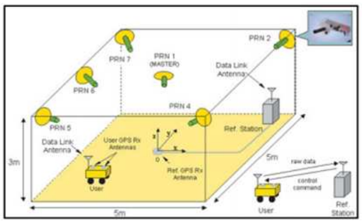
- Increasing need of the navigation systems in indoor environment (hospitals, rescue services, universities,...) – GNSS signal can´t be used
- WiFi
- Radio Frequency
- **Pseudolites** - use of the navigational signal similar to GNSS, supplement of the GNSS signal (tunnels, indoor environment)
- Visual techniques
- Inertial navigation



Indoor navigation technologies

- Increasing need of the navigation systems in indoor environment (hospitals, rescue services, universities,...) – GNSS signal can´t be used
- WiFi
- Radio Frequency
- Pseudolites

- **Visual techniques** – localization is provided by evaluation of the reference objects placed on the characteristic places in the building
- Inertial navigation

Indoor navigation technologies

- Increasing need of the navigation systems in indoor environment (hospitals, rescue services, universities,...) – GNSS signal can´t be used
- WiFi
- Radio Frequency
- Pseudolites
- Visual techniques

- **Inertial navigation** – trajectory determination provided by the measurements from the inertial sensors (accelerometer, gyroscope)
- IPIN - International Conference on Indoor Positioning and Indoor Navigation (organized every year since 2010)

Determining the path of pedestrian movement in indoor environment

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- The use of inertial sensors built in the smartphone to determine the trajectory of pedestrian movement
- Smartphone – basic equipment all of us

Advantages of inertial sensors usage:
- Availability
- Independence (no need for information from external sources)
- Price

Disadvantages of inertial sensors usage:
- Relative position determination
- Need to know the initial position and orientation of the device
- Accuracy of the position rapidly decreases with time measurement (accumulation of errors in the integration process)

- Trajectory determination - base for the navigation in indoor spaces (step detection method), smartphone – low cost solution, expected accuracy 1m

System architecture

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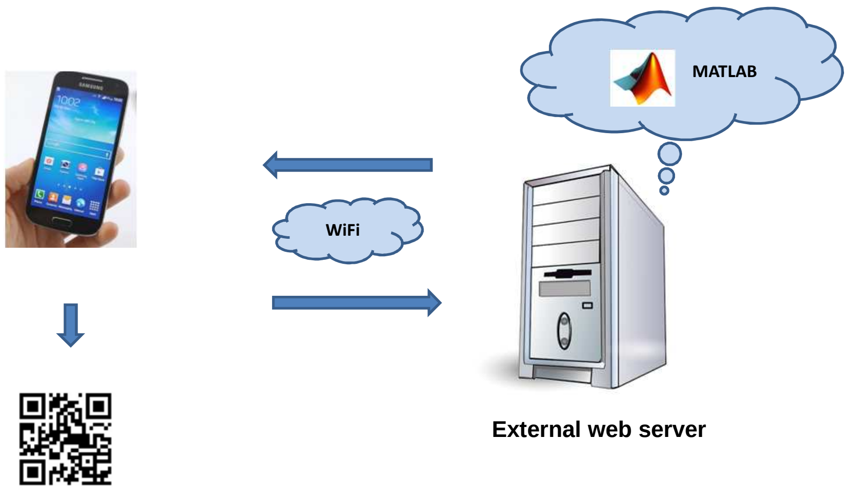

Data acquisition

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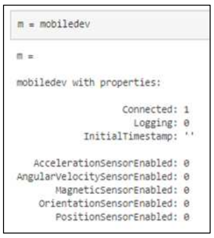
Data acquisition:

- Matlab- Android support (version 2014a)
- Automated acquisition of the measured data



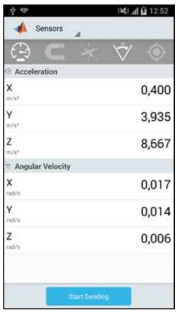
```
m = mobiledev

m =

mobiledev with properties:

                Connected: 1
                  Logging: 0
         InitialTimestamp: ''

 AccelerationSensorEnabled: 0
AngularVelocitySensorEnabled: 0
    MagneticSensorEnabled: 0
 OrientationSensorEnabled: 0
    PositionSensorEnabled: 0
```



Inertial sensors used in the calculation:

- Accelerometers (linear motion)
- Gyroscopes (rotation)

Double integration

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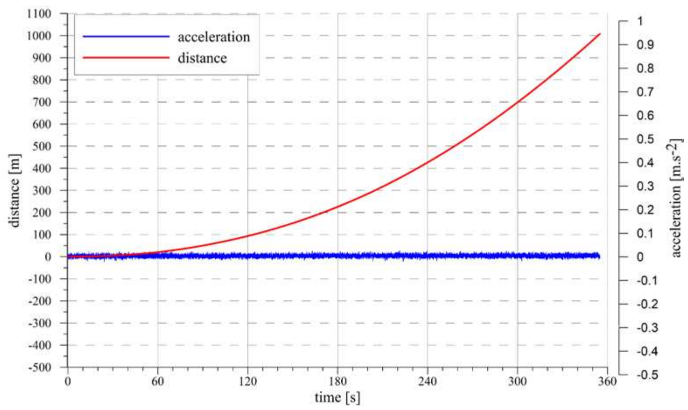
- Trajectory determination using double integration ⟶ error accumulation

$$s = \iint a \,.\, dt$$

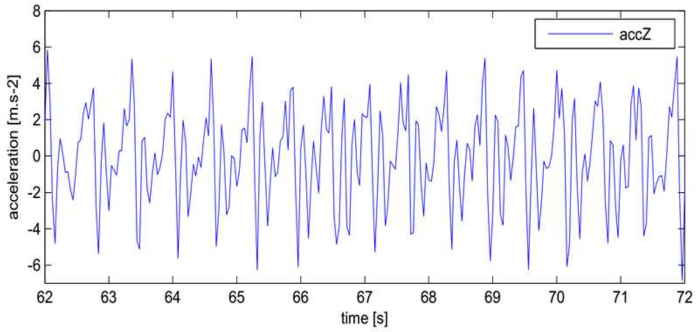
s trajectory
a acceleration
dt time difference



Step detection

Principle:

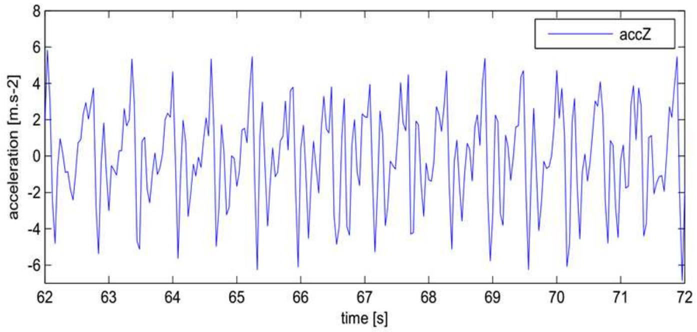
- Step – specific type of mechanical movement
- Changes in the acceleration
- Based on the measured acceleration, steps can be detected (benefit - double integration is not used)
- Orientation of the device - determined from the angular velocity (gyroscopes)
- Direction of the +*Z* axis - down (identical to the direction of gravity)
- Movement of pedestrian - a periodic character



Step detection

Options of step detection:

- from the acceleration magnitude
- from the residues of the acceleration norm
- from residues of acceleration in the *Z axis* direction
- velocity of movement along the *axis Z*



The principle of calculation of the pedestrian trajectory by step detection

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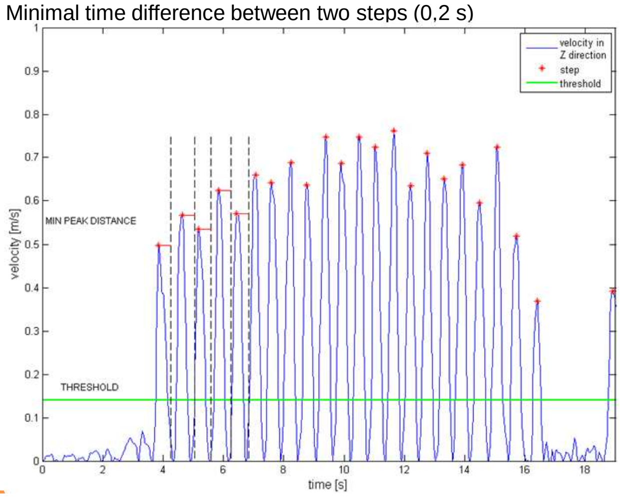
- Step detection from peaks, length determination - use of a known averaged step length (acquired by previous experiment)
- Threshold (limit search of peaks)
- Minimal time difference between two steps (0,2 s)



$$s = N \,.\, \bar{d}$$

s trajectory
N number of detected steps
$\bar{d}$ average step length

The principle of calculation of the pedestrian trajectory by step detection

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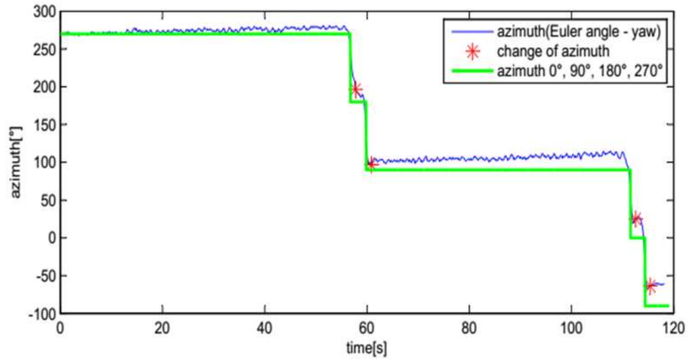
Calculation of the pedestrian orientation (orientation of the steps):

- Calculation of the Euler angle *yaw* (rotation around the Z axis) by the numerical integration of the angular velocity,
- Movements restricted to 4 main directions - 0°, 90°, 180°, 270° (rectangular arrangement of corridors)
- Orientation refers to the initial orientation of the pedestrian (resp. smartphone)



Determination of the trajectory – average step length

- Average of user´s step length, acquired by the previous experiment for the specific user
- Initial position and orientation

Location of pedestrian determined by the polar method:

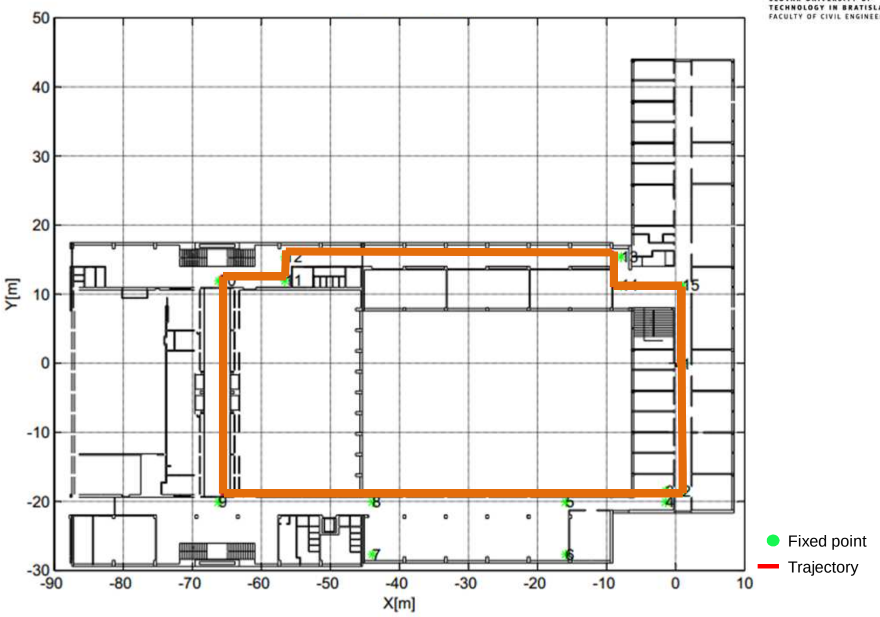
$$X_{(t)} = X_{(t-1)} + step.\cos\left(azimuth_{(t)}\right)$$
$$Y_{(t)} = Y_{(t-1)} - step.\sin\left(azimuth_{(t)}\right)$$

step - step length

azimuth - orientation of the step (4 main directions)

t - number of step

Trajectory – Department of Surveying, STU in Bratislava



Adaptive step length estimation

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Disadvantages of proposed algorithm (averaged step length)

- Constant step length
- Different step length for each user
- Length difference of the whole trajectory (203.80 m) ⟶ 6.20 m

SOLUTION

ADAPTIVE STEP LENGTH

(linear combination of the walking frequency and the acceleration variance)

OFFERS

- Variable step length
- Change in the step length during natural walk
- Better accuracy

Adaptive step length estimation

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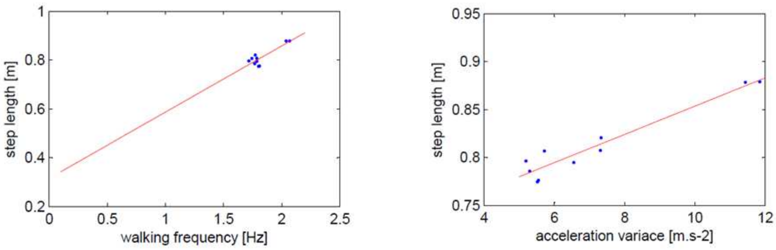
- Variation determined by the linear combination of the walking frequency and the acceleration variance from the several series of measurements

$$SL = \alpha.WF + \beta.AV + \gamma$$

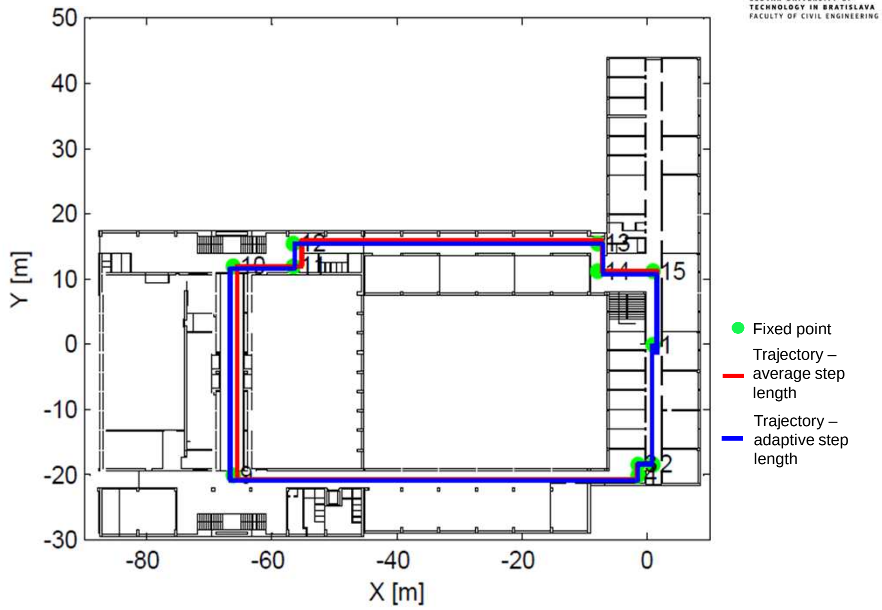
α, β, γ - parameters of the adaptive step length estimation, individual for each user

WF - walking frequency, $WF = \frac{1}{t_k - t_{k-1}}$

AV - acceleration variance, $AV = \frac{1}{n-1}\sum_{k=1}^{n}(a_k - \bar{a})^2$



Trajectory



Achieved results

	Number of steps		*Length of the section [m]*			*Difference [m]*	
Section	*Actual*	*Detected*	*Actual length*	*Average step length*	*Adaptive step length*	*Average step length*	*Adaptive step length*
1 - 2	21	21	18,40	16,80	17,14	1,60	1,26
2 - 3	4	4	2,40	3,20	3,12	-0,80	-0,72
3 - 4	2	2	1,60	1,60	1,40	0,00	0,20
4 - 9	77	76	64,00	60,80	63,31	3,20	0,69
9 - 10	38	38	32,00	30,40	31,77	1,60	0,23
10 - 11	12	12	9,60	9,60	9,50	0,00	0,10
11 - 12	5	5	3,50	4,00	3,88	-0,50	-0,38
12 - 13	61	59	48,70	47,20	49,70	1,50	-1,00
13 - 14	6	5	4,20	4,00	4,16	0,20	0,04
14 - 15	12	12	8,10	9,60	9,65	-1,50	-1,55
15 - 1	14	13	11,30	10,40	11,19	0,90	0,11
Suma	252	247	203,80	197,60	204,82	6,20	-1,02

Conclusions

- Pedestrian trajectory determination using smartphones – low cost solution, available for large part of population
- The advantage of the adaptive step length determination - simplicity of calculation algorithms, reflected specific characteristics of the user´s walk
- Step detection could be applied for pedestrian trajectory determination – accuracy of proposed algorithm 1 m

Future work

- Definition of the control points - correction of the calculated trajectory (e.g. scanning RFID tags with exact position) in the field of possible movement
- Floor plan may be replaced by 3D model of the building

Pedestrian Trajectory Determination in Indoor Environment

Thank you!

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