Friedrich-Alexander-Universität
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IoT for Healthcare

Trade-Offs Between Diagnosis and Usability

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Agenda

1. IoT for Healthcare
2. Stakeholders and their Interests
3. Example Conflict of Objectives: Diagnostic Information vs. Energy Consumption
4. Approach 1: Sensor Selection
5. Approach 2: Data Preselection
6. Conclusion

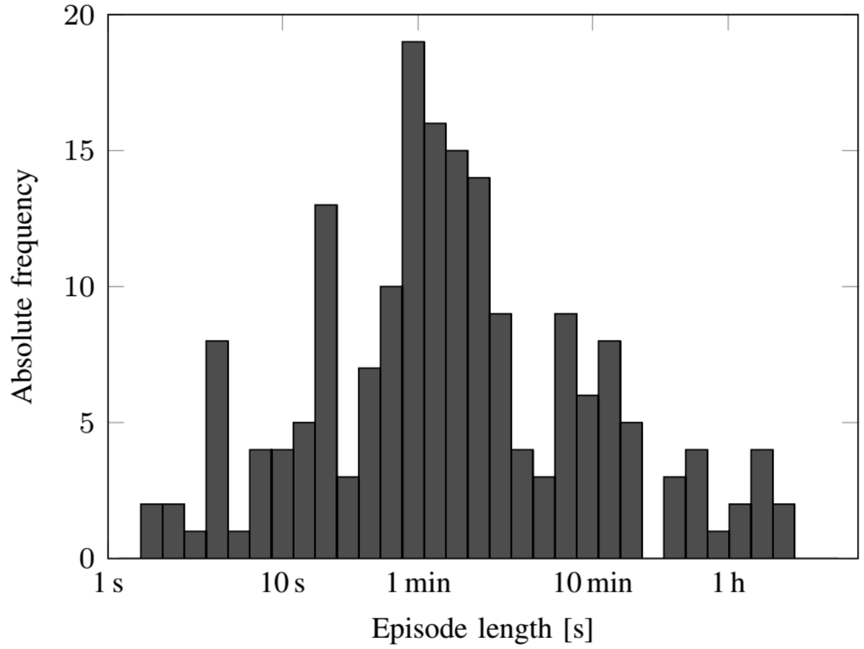
IoT for Healthcare

Why to Continuously Monitor Vital Signs?

Example 1: Atrial fibrillation

Duration of an AF episode: mostly < a few minutes

⇨ **Diagnosis of diseases with transient symptoms**



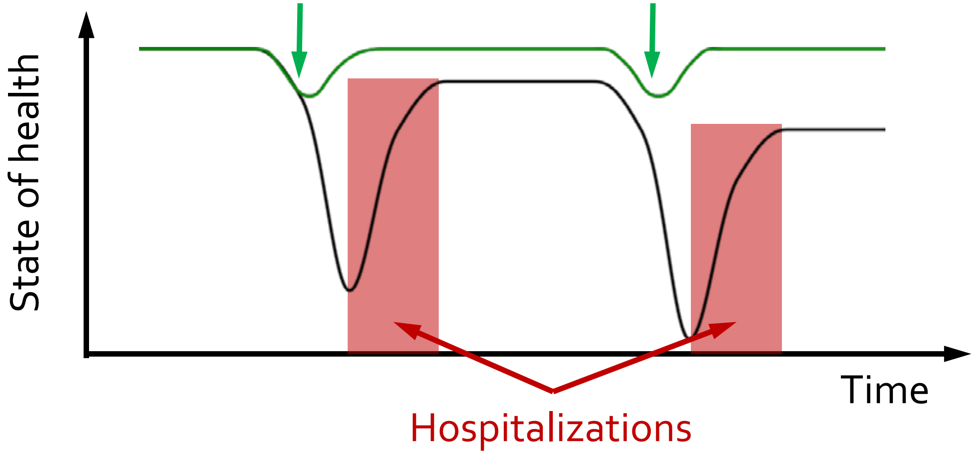
Kirchner J, Schild S, Fischer G. 2017 IEEE Int Symp Med Meas Appl (MeMeA), 320–325.

Why to Continuously Monitor Vital Signs?

Example 2: Acute cardiac decompensation

Regular follow-ups: every 3–6 months

Time for development of acute decompensation: ~ 1–2 weeks



⇨ **Improved therapy by quick adaptation to the patient's needs**

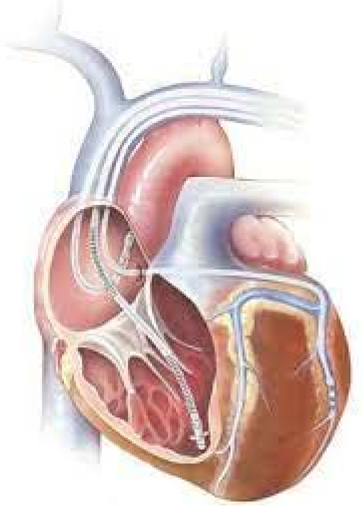
- Sensor–actor systems
- Feedback to patient
- Feedback to treating physician

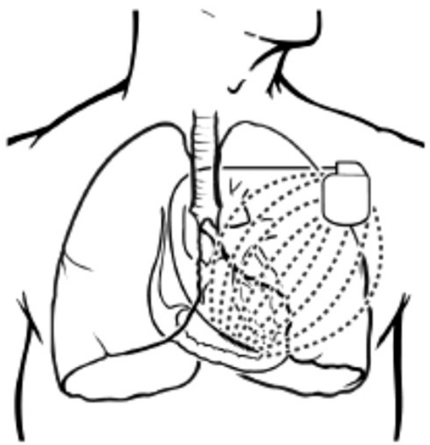
Why to Continuously Monitor Vital Signs?

Example 2: Acute cardiac decompensation

Sensors

- Intracardiac ECG
  (morphology & heart rate)
- Activity
- Thoracic impedance
- Intracardiac impedance
- Blood pressure
- Body weight





Boston Scientific, http://www.columbia.edu/itc/hs/medical/hickey/docs/Pacemaker,%20ICD%20and%20CRT%20Overview%20022007.pdf
L. Wang, Am. J. Cardiol. 99 (10), Suppl., 2007, S3-S10

Information beyond Diagnostic Markers

Example 3: Activity Classification

Purpose: Context information for interpretation of other sensor data
Indicator for decreased physical capability

Challenge: Properly distinguish different states of physical/mental load and disease-related causes
e.g. – running
– recumbent bike
– exciting movie
– cardiac disease

⇨ **Fusion of different sensors / IoT devices needed for sensitive and specific diagnostic markers and context information**

The Top 10 in Burden

Disease	Lifetime prevalence [%]	Fraction of deaths [%]	Fraction of costs [%]	Fraction of YLD metric [%]
Hypertensive heart disease	**20–30**	3.7	**3.7**	0.1
Atrial fibrillation & Congestive heart failure	**15** **2**	**10.9**	3.1	2.2
Diabetes mellitus	**6–7**	2.6	2.6	**5.6**
Ischemic heart disease	5–10	**16.0**	2.5	1.3
COPD & Asthma	5–8 5	3.1	2.1	**3.9**
Dementia	3	1.5	**4.3**	**3.0**
Kidney disease	2–12	2.1	0.5	1.6
Stroke	2–3	**7.5**	**3.3**	0.9
Parkinson's disease	2	0.7	0.9	0.2
Pneumonia	2	2.6	0.6	0.7

Ranges indicate different published figures. Cancer not considered.
[Bauer S. Master's thesis, LTE/FAU, 2017]

Comorbidities

	Hypert. heart dis.	Atrial Fibrill.	Diabetes	Ischemic heart dis.	COPD	Asthma	Dementia	Kidney dis.	Stroke	CHF	Parkinson	Pneumon.
Hypertensive heart disease			X		X			X				
Atrial fibrillation												
Diabetes mellitus					X						X	
Ischemic heart disease	X		X		X			X				
COPD												X
Asthma												X
Dementia	X		X	X					X	X	X	
Kidney disease	X		X									
Stroke	X		X	X				X		X		
CHF												
Parkinson disease							X					
Pneumonia					X		X	X	X		X	

Conclusion

Purpose continuous disease monitoring

- Diagnosis of diseases with transient symptoms
- Improved therapy by quick adaptation to the patient’s needs

Diseases for continuous disease monitoring

- Diseases with transient symptoms
- Chronic diseases (cardiovascular, respiratory, renal, metabolic, mental)
- Keep comorbidities in mind!

IoT for continuous disease monitoring

- Sensor fusion for discrimination of different situations in daily life and different disease states

Stakeholders and their Interests

Stakeholders and their Interests

Patient
- ⇨ Diagnostic/Therapeutic quality
- ⇨ Integrability into daily life

Treating Physician
- ⇨ Diagnostic/Therapeutic quality
- ⇨ Integrability into clinical routine

Producer
- ⇨ Profit from investments

Health Insurances
- ⇨ Reduced costs for diagnosis & treatment

Regulatory Authorities
- ⇨ Ethical aspects, particularly patient safety

Stakeholders and their Interests in Summary

Diagnostic/Therapeutic quality

- ⇨ Signal quality
- ⇨ Data evaluation quality
- ⇨ Robustness
- ⇨ Full coverage
- ⇨ Effectiveness of treatment

Integrability into daily life

- ⇨ Non-stigmatization
- ⇨ Light weight, small size
- ⇨ Long battery life
- ⇨ No long cables

⇨ How to achieve sufficient functionality with limited energy?

Argus® II retinal prothesis system
[http://www.secondsight.com]

Example Conflict of Objectives: Diagnostic Information vs. Energy Consumption

Conflict of objectives

Diagnostic information

- Increase number of sensors for more information
- Increased amount of transmitted data for data fusion

Battery lifetime

- Decrease number of sensors
- Decrease amount of transmitted data

… for lower power consumption

Approach 1: Sensor Selection

Idea

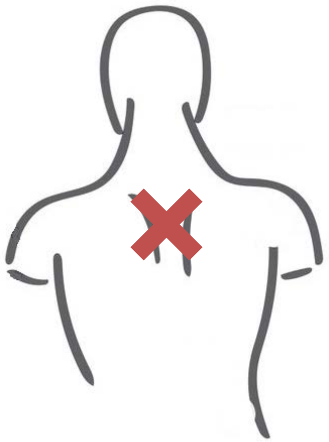
When selecting the sensors for diagnosis, consider both ...

- relevance for diagnostic purpose and
- power consumption

Example Activity Classification: Concept

Sensor Platform

- Sensors: accelerometer
  gyroscope
  barometer
- Sensor position: upper back
- Arduino micro



Power consumption of sensor modules

Gyroscope	11,880 µW
Accelerometer	1,650 µW
Barometer	3 µW

⇨ Power consumption dominated by gyroscope

MPU-6000 and MPU-6050 Product Specification Revision 3.4, InvenSense, Inc.
MS5611-01BA03 Barometric Pressure Sensor, with stainless steel cap, Measurement Specialties, Inc.

Example Activity Classification: Methods

Activities for Classification

- Standing
- Walking in the flat
- Walking upstairs / downstairs
- Jogging

Study Population

- *N* = 20 (9/11 male/female)
- 24 ± 4 years old (21–38yr)

Data Analysis

- 261 features derived from sensor data
- *k* nearest neighbor algorithm
- Optimization w.r.t. F1 score

Example Activity Classification: Results

	Sensor combination						
	A+G+P	A+G	A+B	G+B	A	G	B
F1 score [%]	95.7	95.1	95.0	93.6	91.4	90.9	62.1
Power consumption [mW]	13.5	13.5	1.7	11.9	1.7	11.9	0.003
Normal. computation time [%]	100	92	55	44	39	41	92

A: accelerometer; G: gyroscope; B: barometer
J. Kirchner, S. Faghih-Naini, P. Bisgin, G. Fischer, 2018 IEEE SENSORS, pp. 1-4

⇨ With reduced sensor set: power reduced by 88%
computation time by 45%
F1 score worsened by only 0.7%

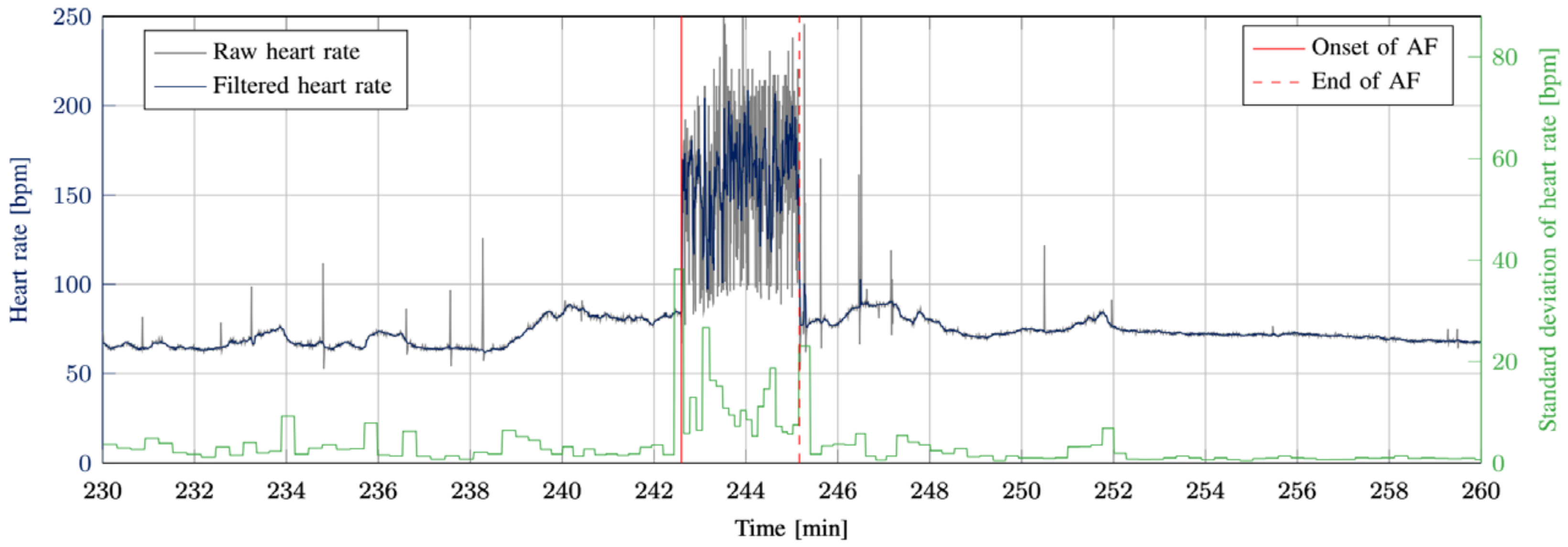
Approach 2: Data Preselection

Idea

- Data pre-analysis "at the edge"
- Identify and transmit only data that might be diagnostically relevant
- Computationally demanding data analysis after data transmission

Example Detection of Atrial Fibrillation: Concept

- Identify data segments that might contain AF episodes
- Discard data segments with clear normal sinus rhythm (NSR)
- Optimize selection algorithm for maximum sensitivity



Example Detection of Atrial Fibrillation: Methods

Database

- PhysioBank: MIT-BIH Atrial Fibrillation Database
- 16 usable recordings from patients with AF (10h duration each)
- 184 AF episodes
- Fraction of AF of entire data: ~37 %

Detection Algorithm for preselection

- A-posteriori analysis
- Detection criterion:
  standard deviation of heart rate > threshold
- Optimization of free parameters w.r.t. max.
  sensitivity = $\frac{\text{\# data segments with correctly detected AF}}{\text{\# data segments with AF}}$
- Alternative optimization (“stand alone”):
  sensitivity = specificity

Goldberger AL et al. Circulation 2000; 101(23): e215–e220.
Moody GB, Mark RG. Computers Cardiol 1983; 10(1): 227–230.

Example Detection of Atrial Fibrillation: Results

	"Preselection"	"Stand-alone"
Sensitivity	99.6 %	89.3 %
Specificity	38.4 %	
Episode sensitivity	100 %	100 %
Data reduction (off all data)	26.4 %	61.1 %
Data reduction (off NSR)	38.4 %	89.5 %

J. Kirchner, S. Schild, G. Fischer, 2017 IEEE Int. Symp. Med. Meas. Appl. (MeMeA), pp. 320-325

⇨ Reduction of non-AF data with simple "preselection" algorithm by 38%
with "stand-alone" algorithm (higher specificity) by 90%

Conclusion

Conclusion

Potential Benefits

- Diagnosis of diseases with transient symptoms
- Improved therapy by quick adaptation to the patient’s needs

Potential Conflicts

- Amount of data: functionality vs. power consumption
- Personal data: data protection vs. data for product improvement
- …

Potential Solutions

- Sensor selection
- Data preselection (data evaluation “at the edge”)

Thanks a lot for your attention!

Questions?