Overview of Capacitive Sensing Applications

Aein Rezaei

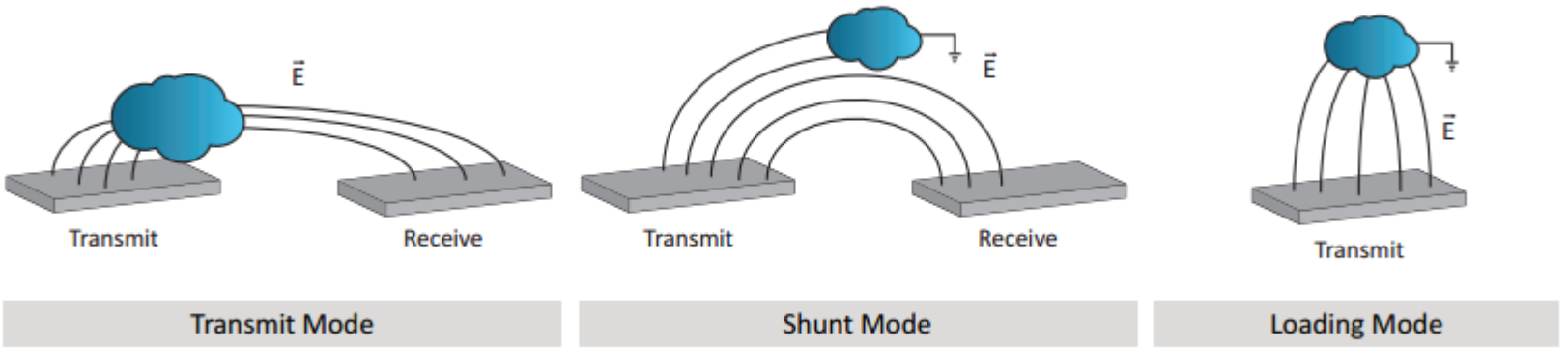


Figure 1. Measurement modes for capacitive proximity sensing.

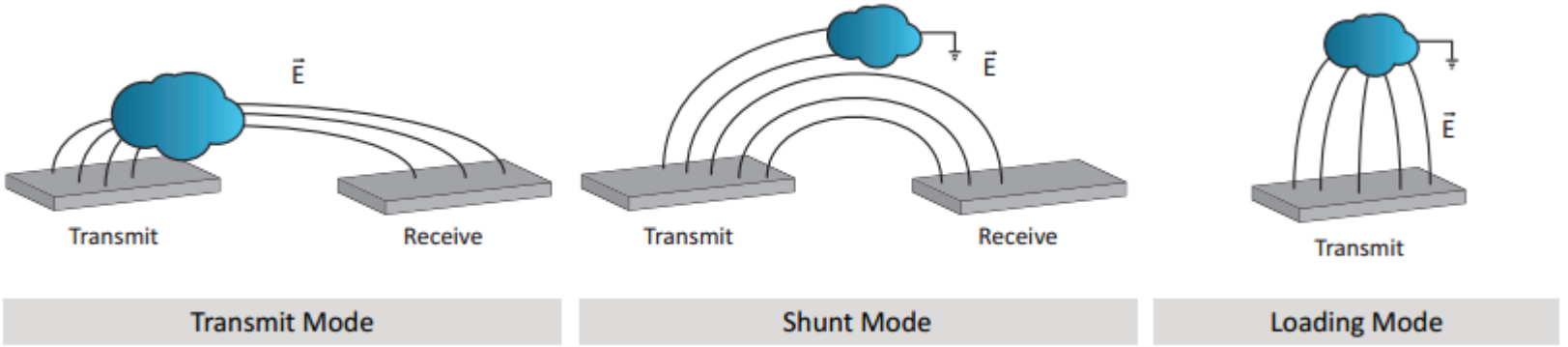
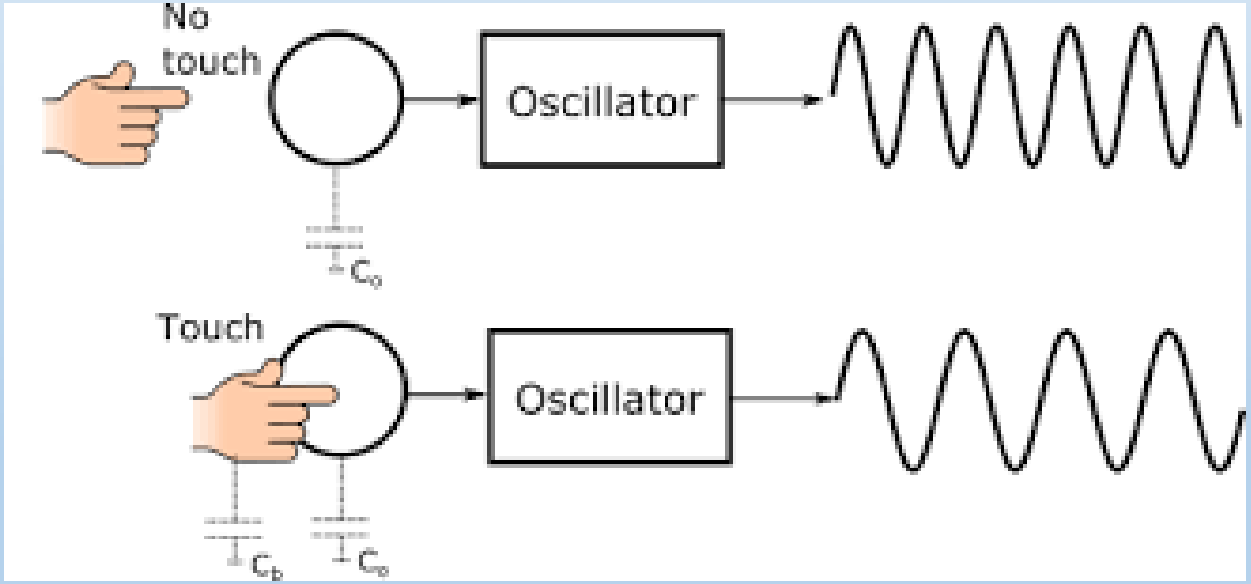
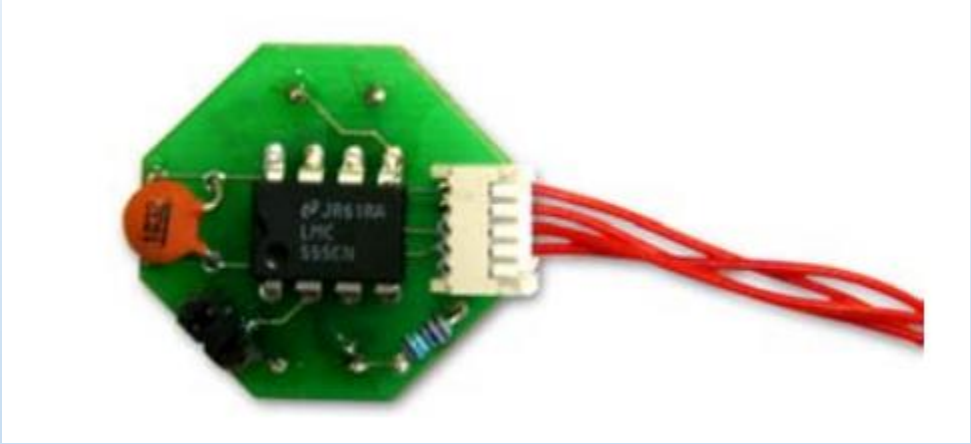


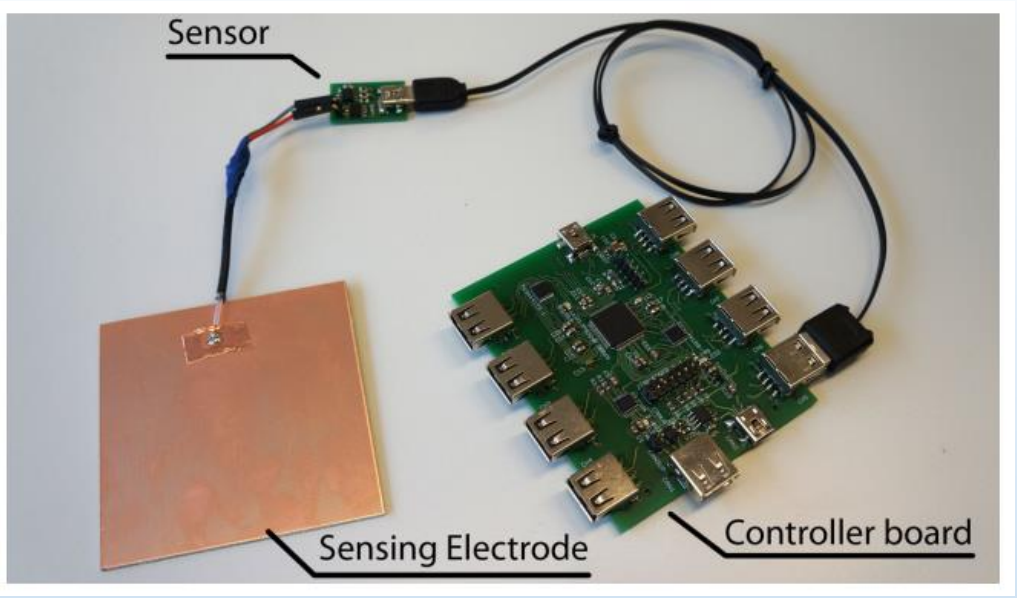
Figure 1. Measurement modes for capacitive proximity sensing.



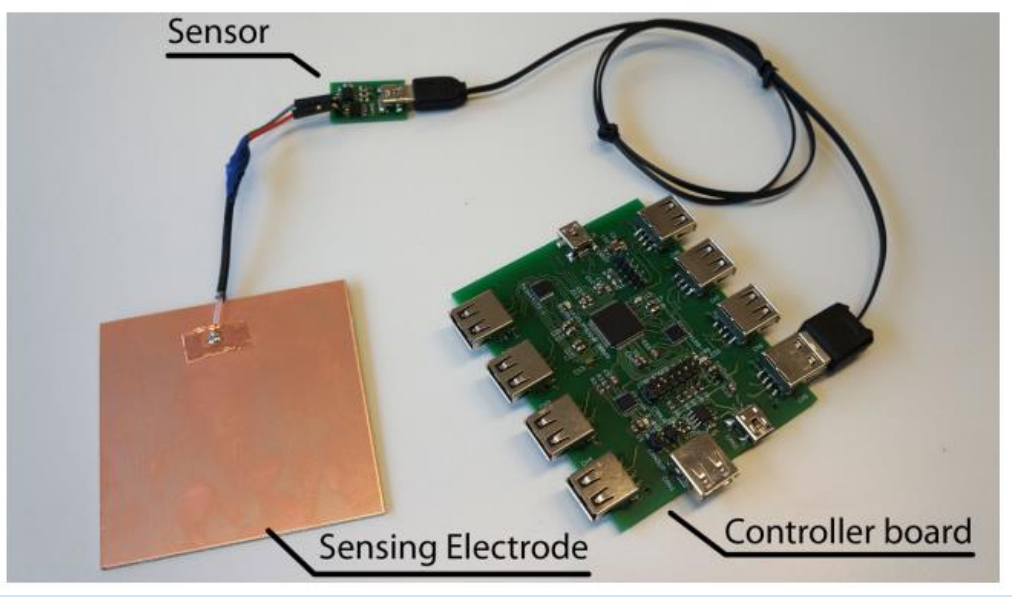
Hardware

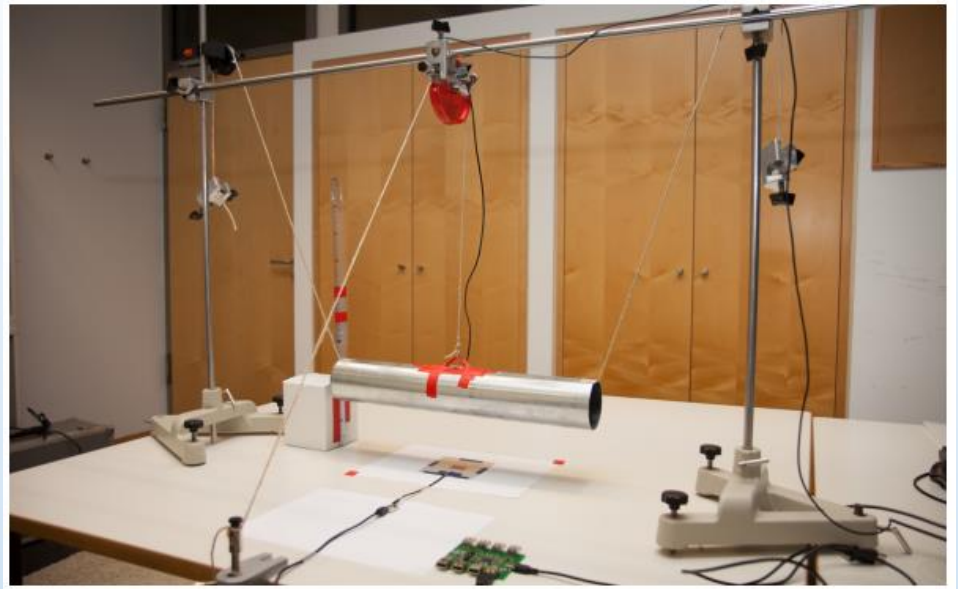


[2] Wimmer, R., Kranz, M., Boring, S. and Schmidt, A., 2007, March. A capacitive sensing toolkit for pervasive activity detection and recognition. In *Pervasive Computing and Communications, 2007. PerCom'07. Fifth Annual IEEE International Conference on* (pp. 171-180). IEEE.



[3] T. Grosse-Puppendahl, Y. Berghoefer, A. Braun, R.Wimmer, and A. Kuijper, “OpenCapSense: A Rapid Prototyping Toolkit for Pervasive Interaction Using Capacitive Sensing,” in *Proceedings PerCom, 2013, pp. 152* – 159.





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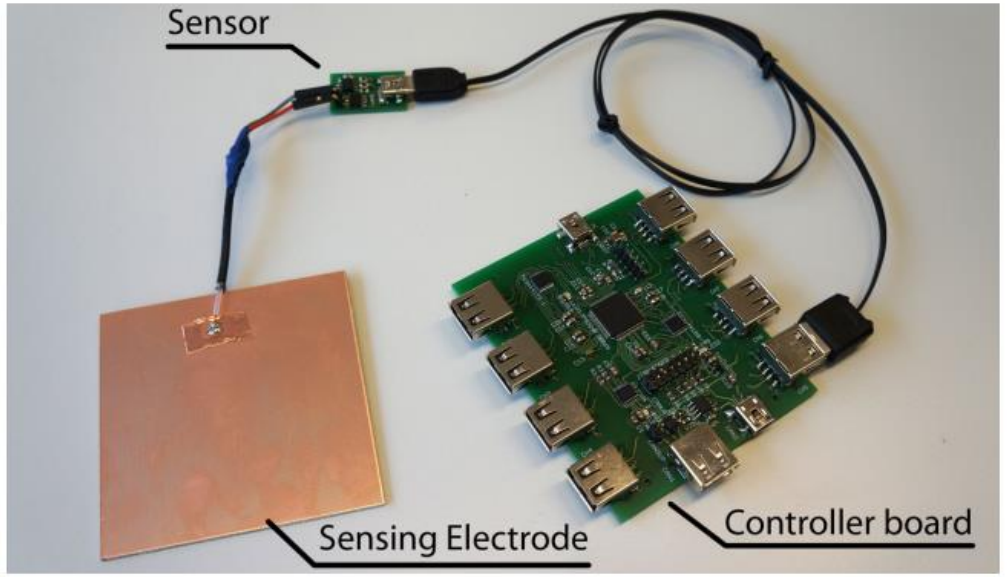

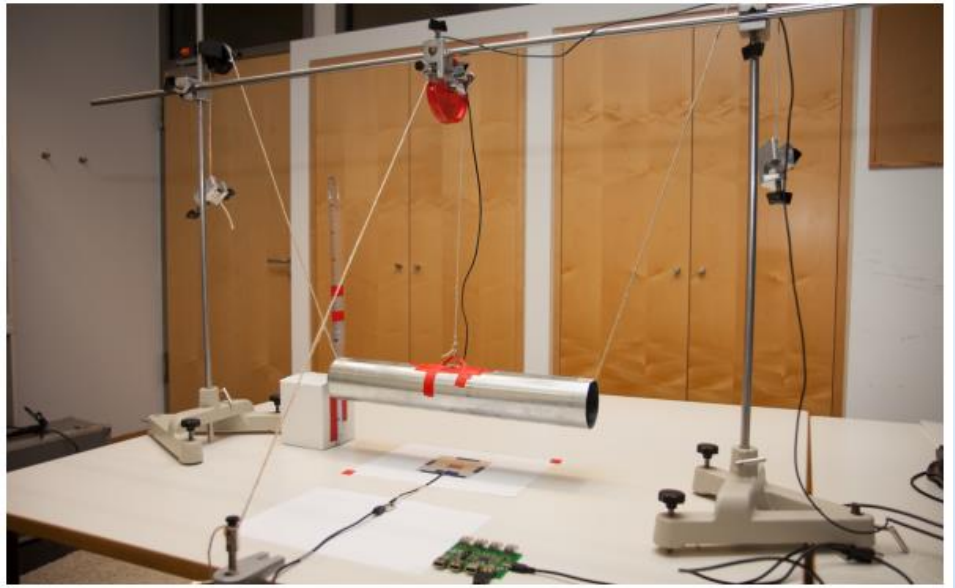

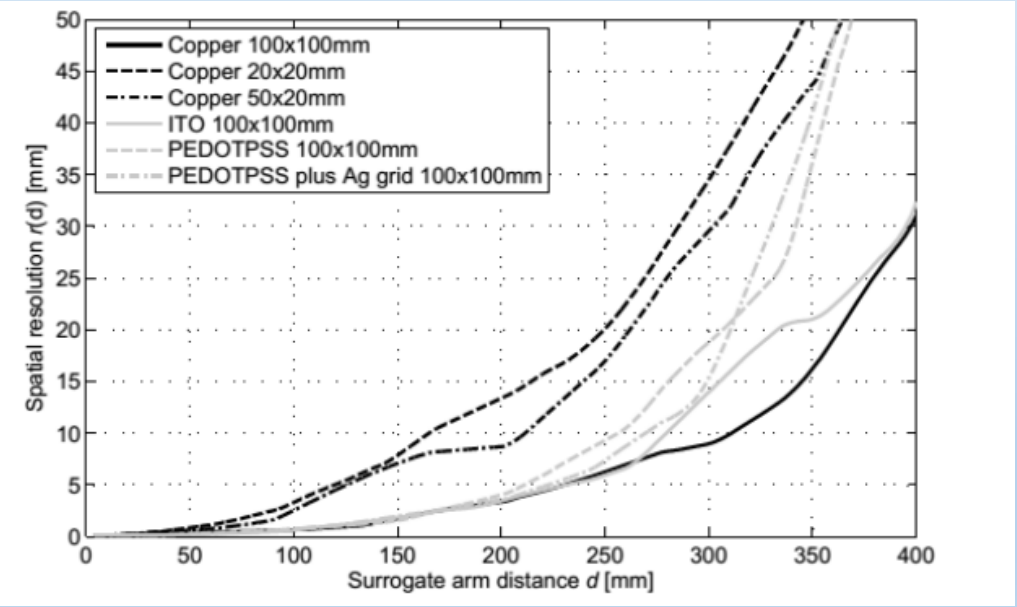

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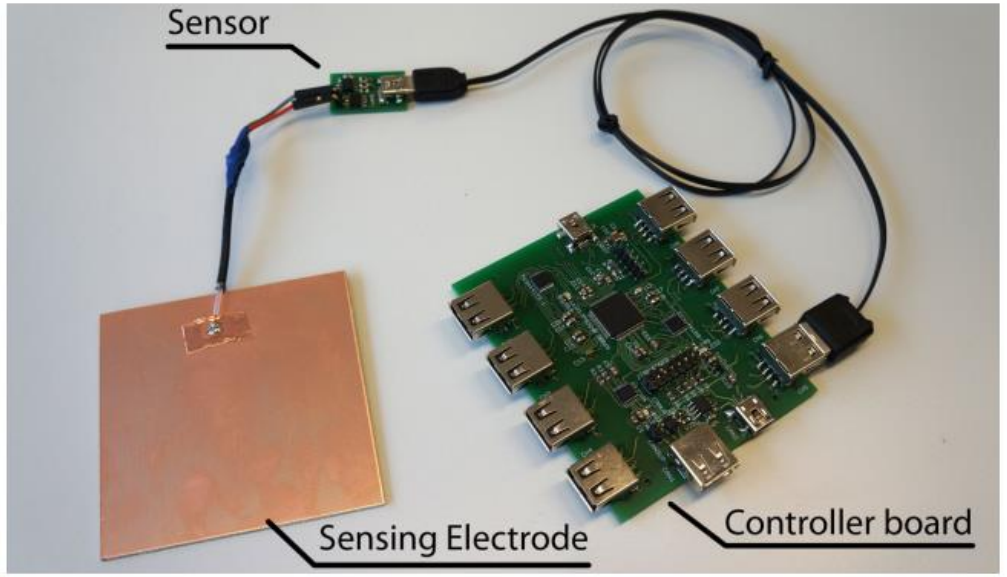

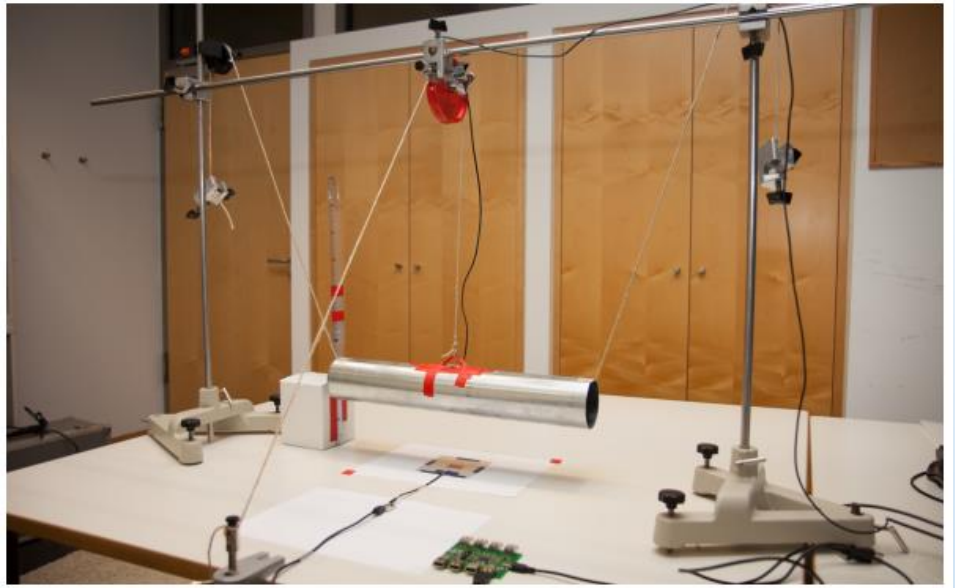

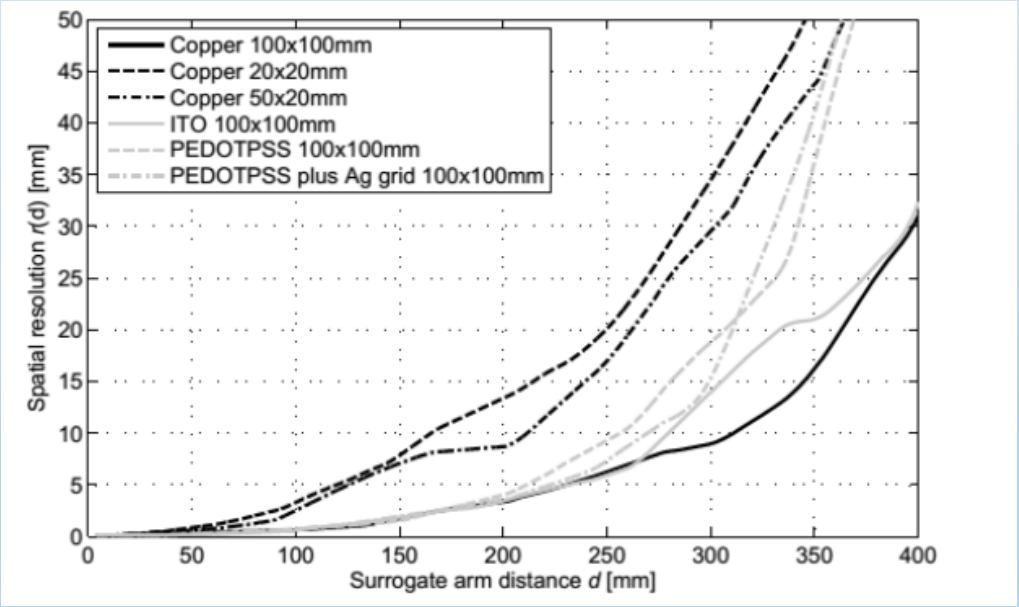

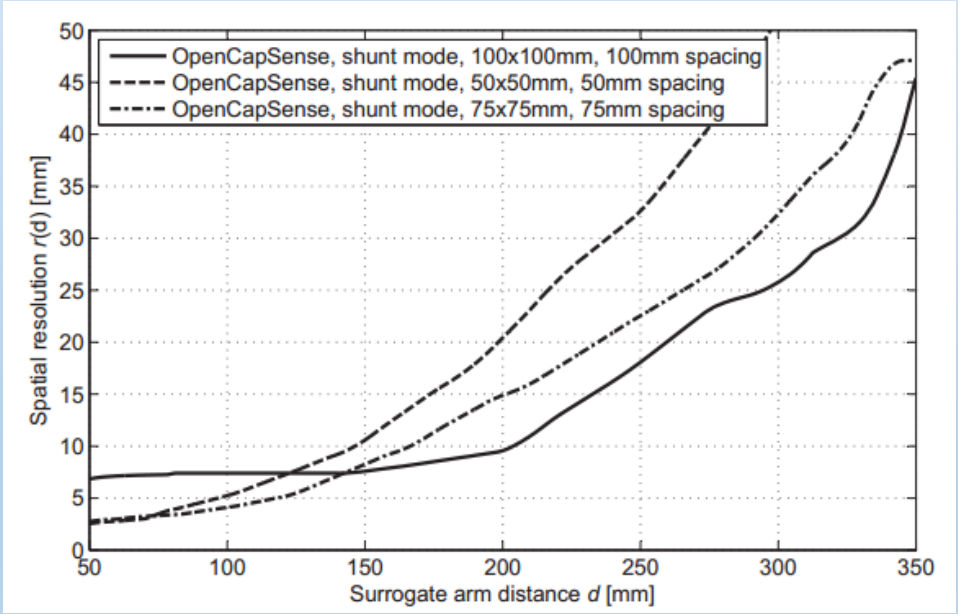

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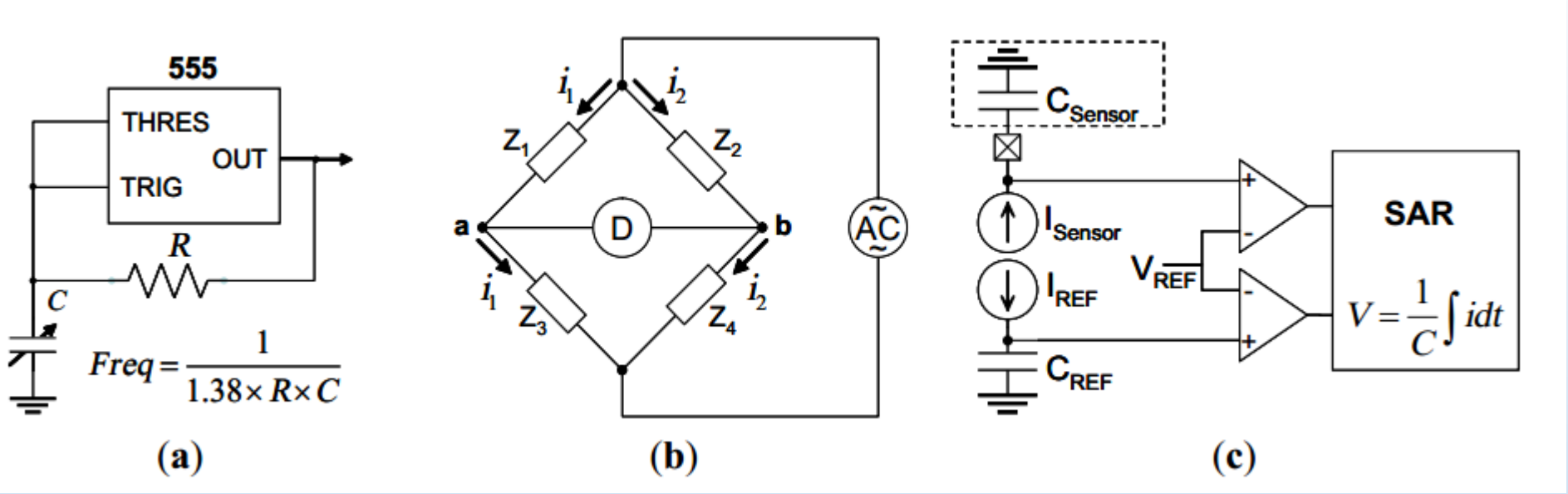
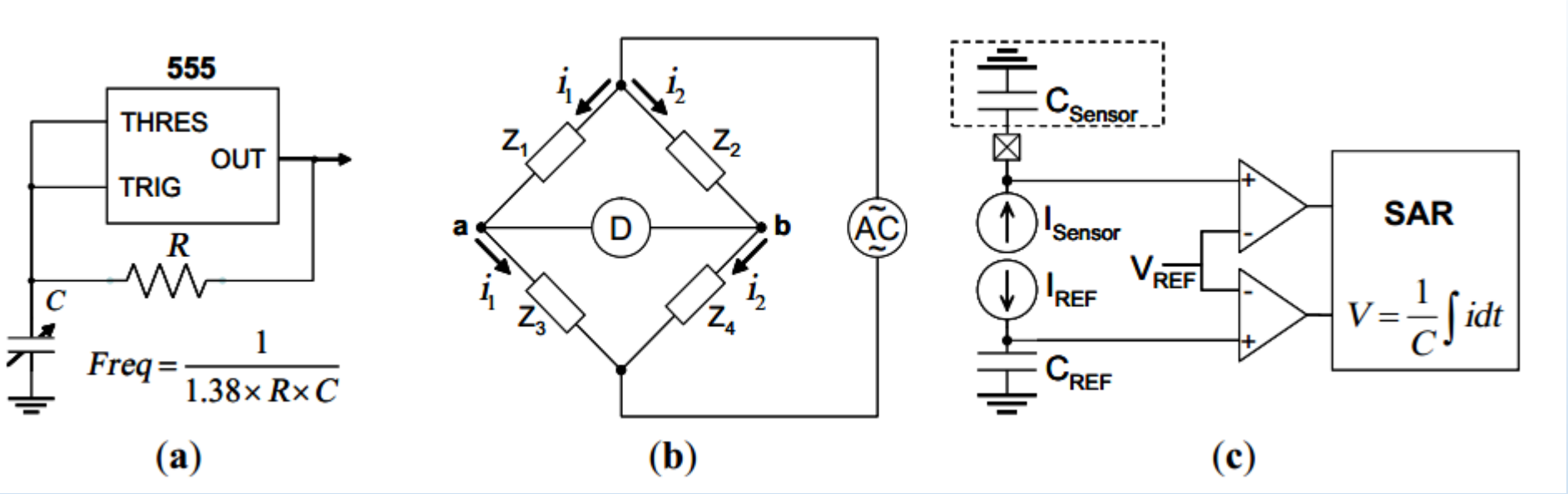


[4]

[4]Chang, Wen-Ying, Chi-Chun Chen, Chih-Cheng Chang, and Chin-Lung Yang. "An enhanced sensing application based on a flexible projected capacitive-sensing mattress." *Sensors* 14, no. 4 (2014): 6922-6937.



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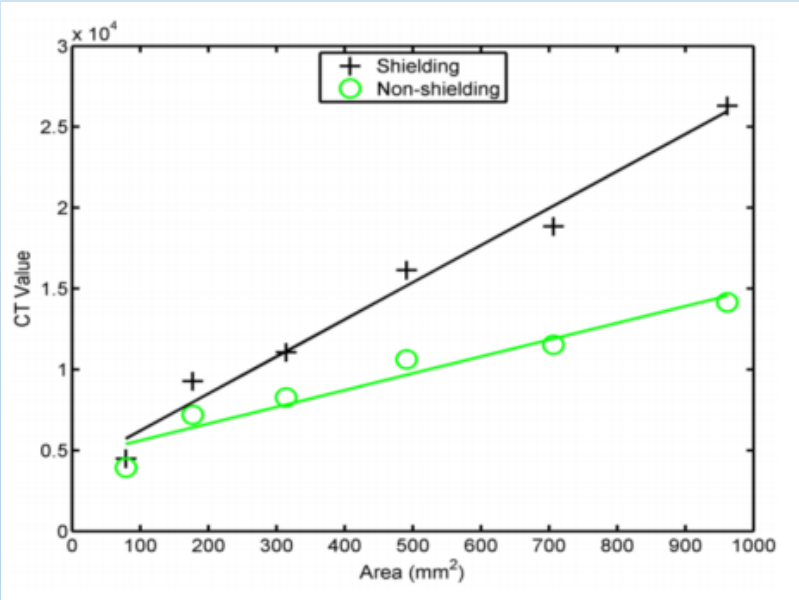

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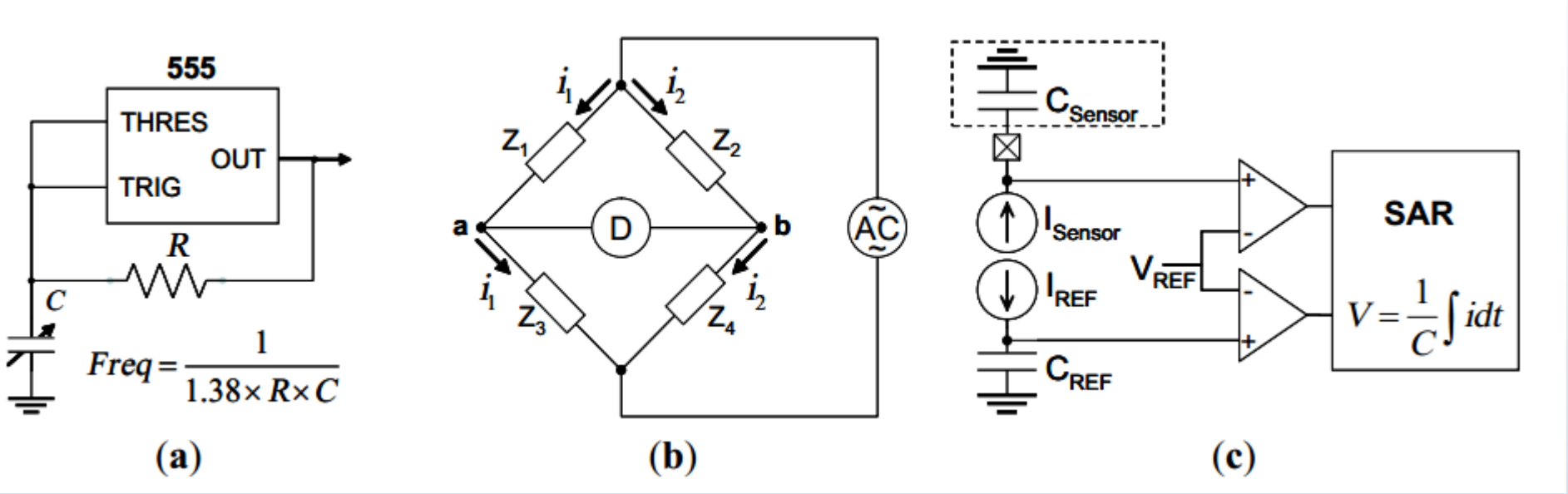

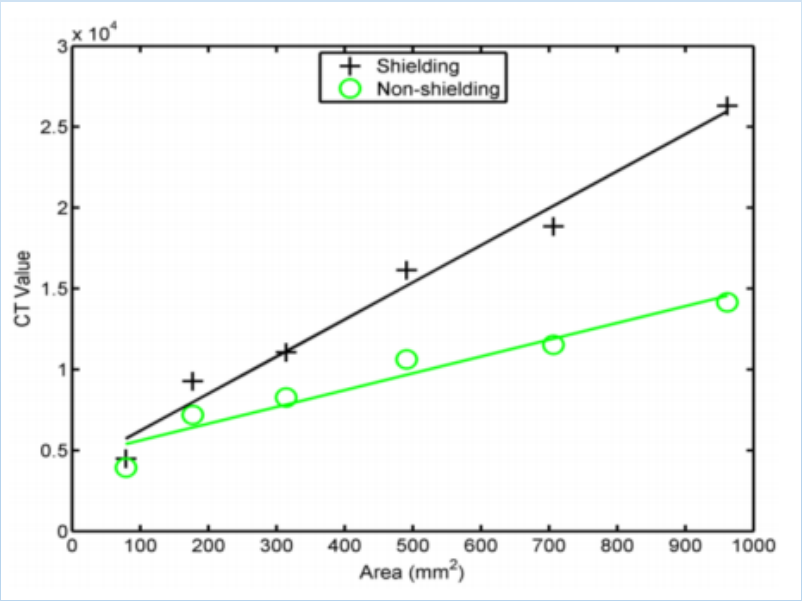

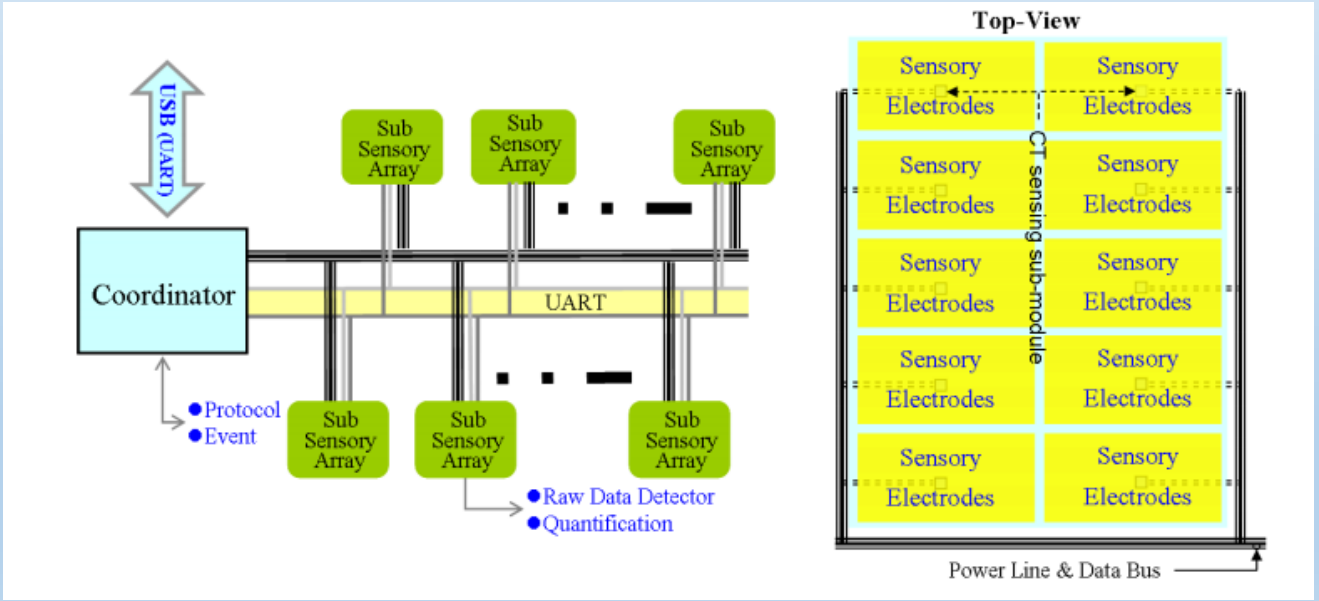

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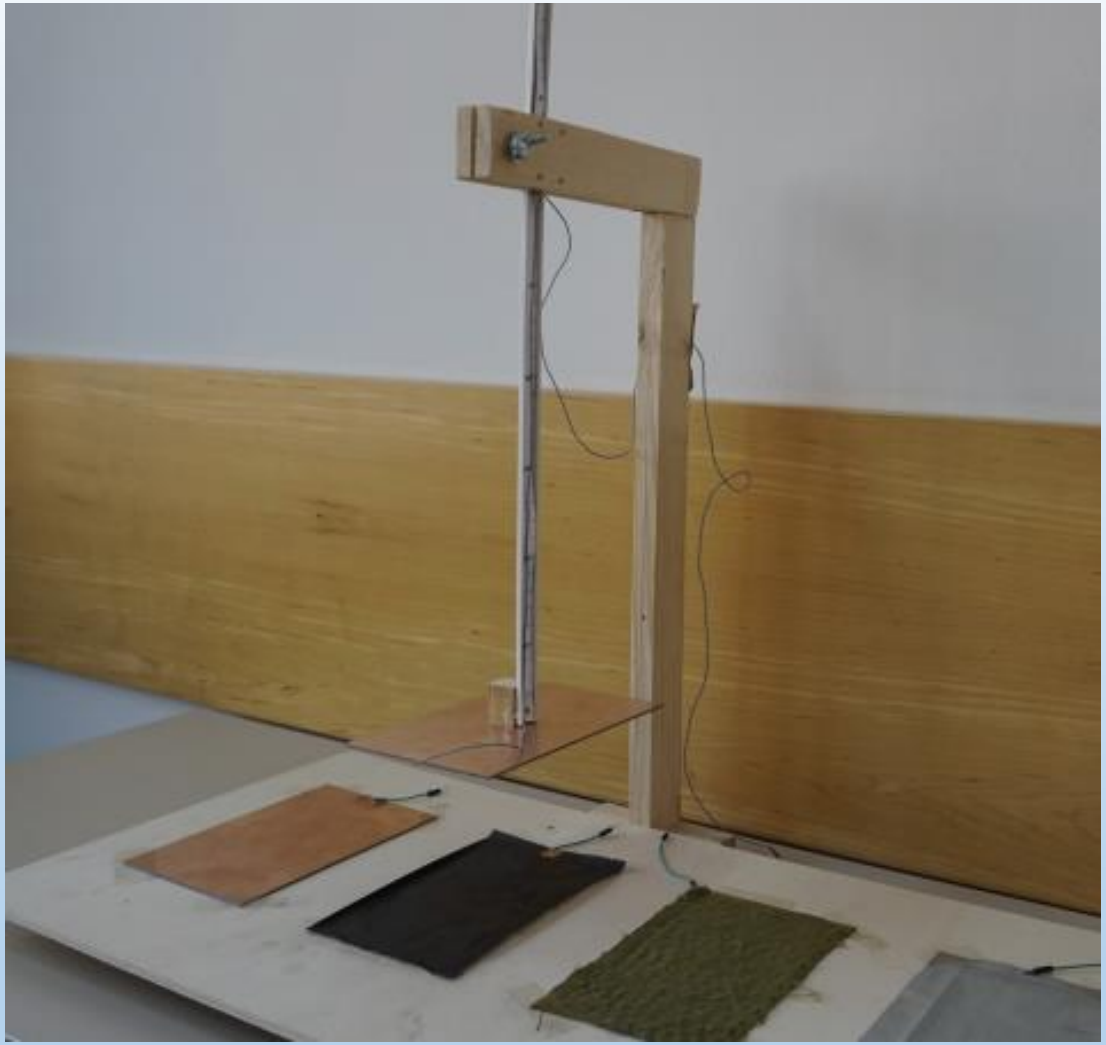
[5] Rus, S., Sahbaz, M., Braun, A. and Kuijper, A., 2015, November. Design factors for flexible capacitive sensors in ambient intelligence. In *European Conference on Ambient Intelligence* (pp. 77-92). Springer, Cham.



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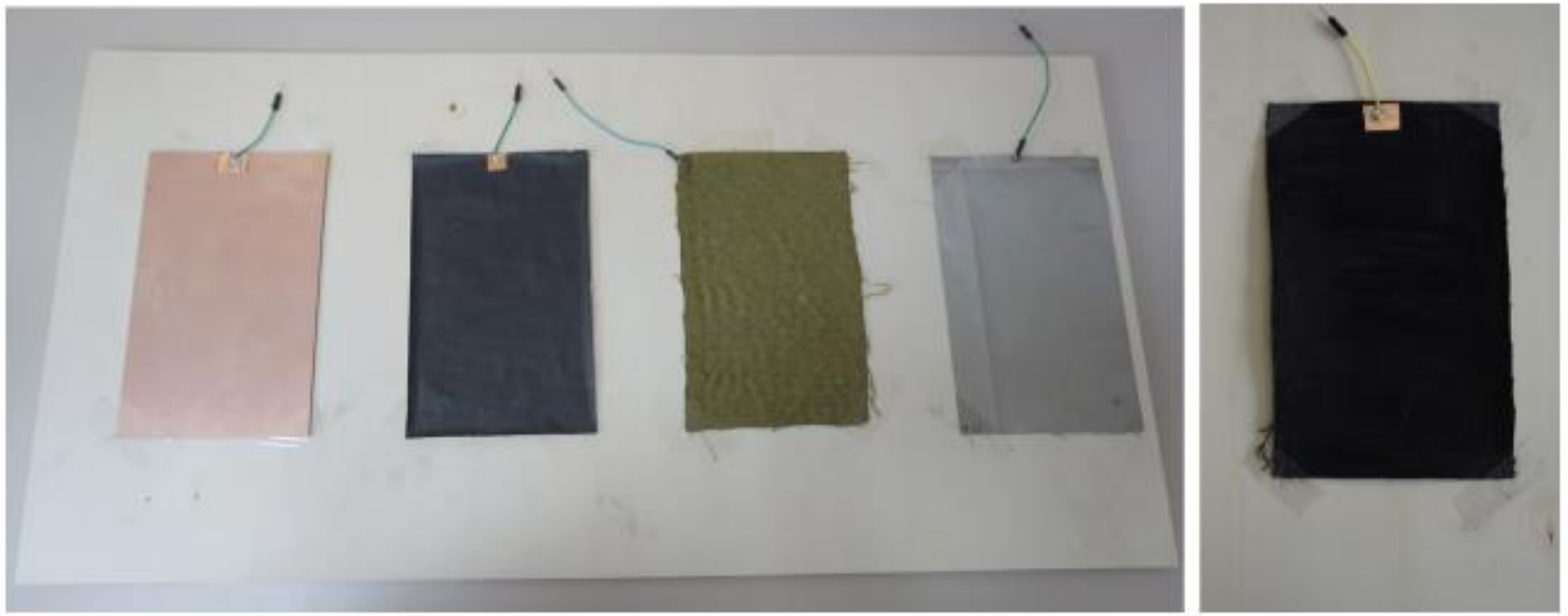

Fig. 2. Electrode materials samples of same size used in self capacitance measurement mode: (from left to right) copper electrode, conductive paint, conductive thread, conductive fabric, conductive paint on fabric

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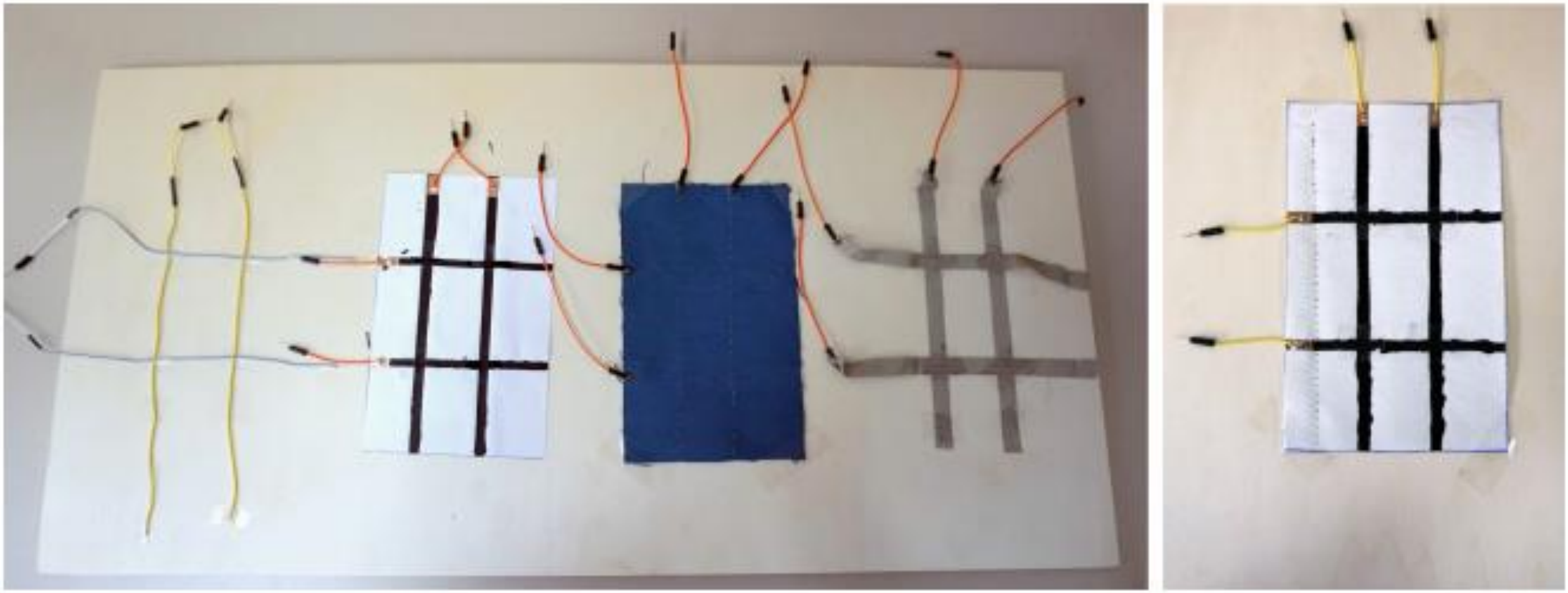

Fig. 3. Electrode material samples of same size used in mutual capacitance measurement mode:(from left to right) copper wires, conductive paint, conductive thread, conductive fabric, conductive paint on fabric

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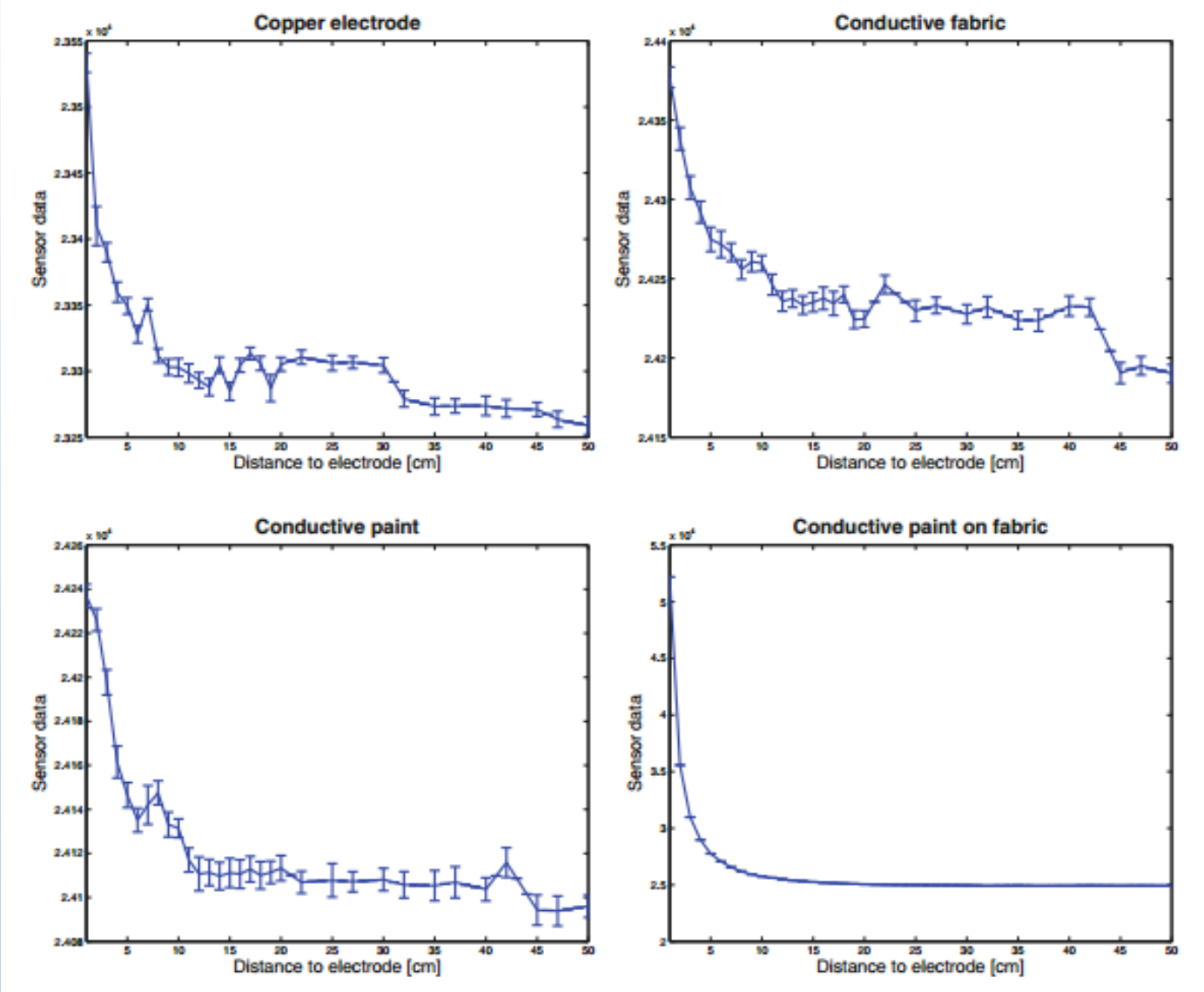

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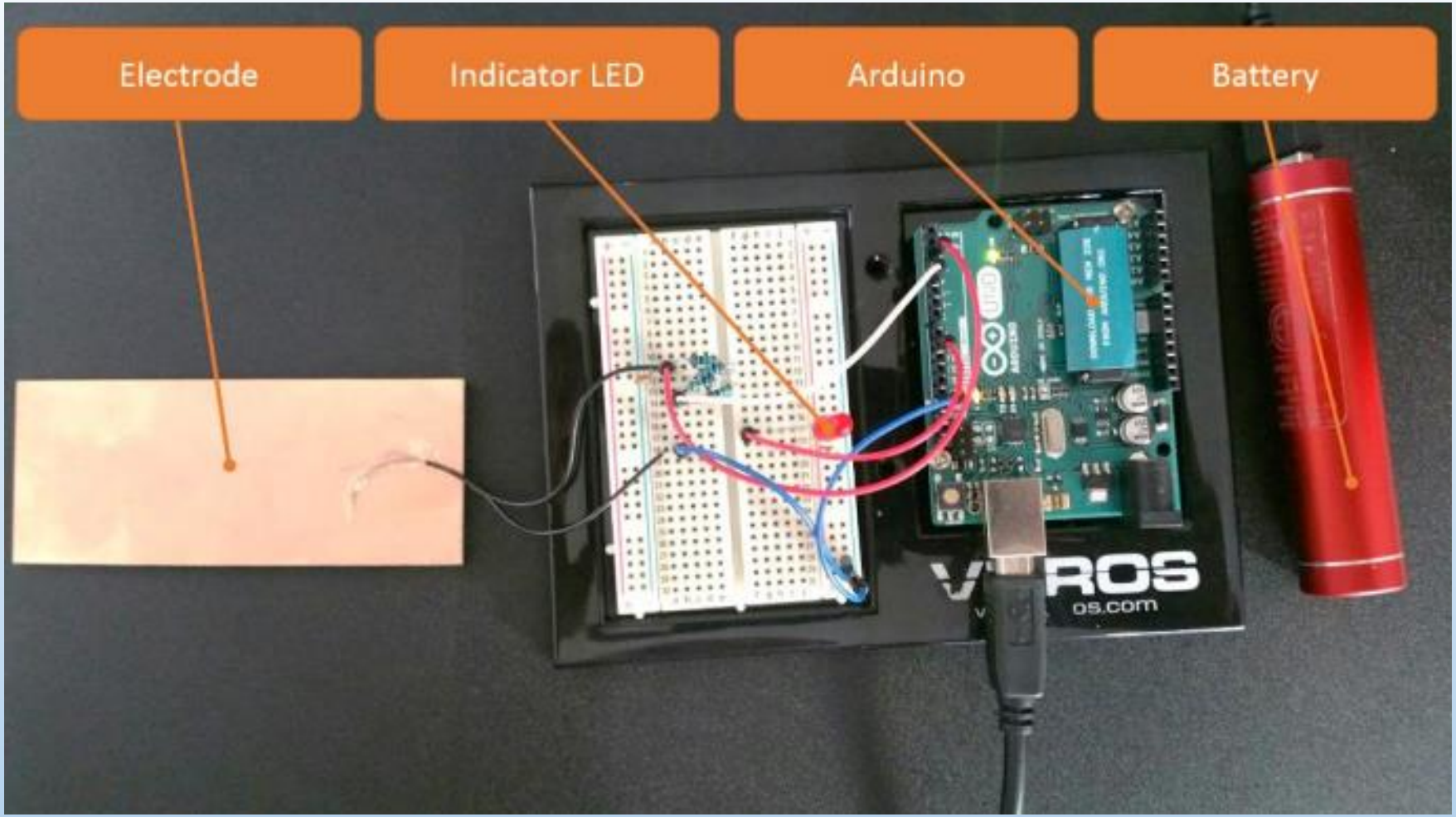

[6] Braun, A., Majewski, M., Wichert, R. and Kuijper, A., 2016, July. Investigating low-cost wireless occupancy sensors for beds. In *International Conference on Distributed, Ambient, and Pervasive Interactions* (pp. 26-34). Springer International Publishing.

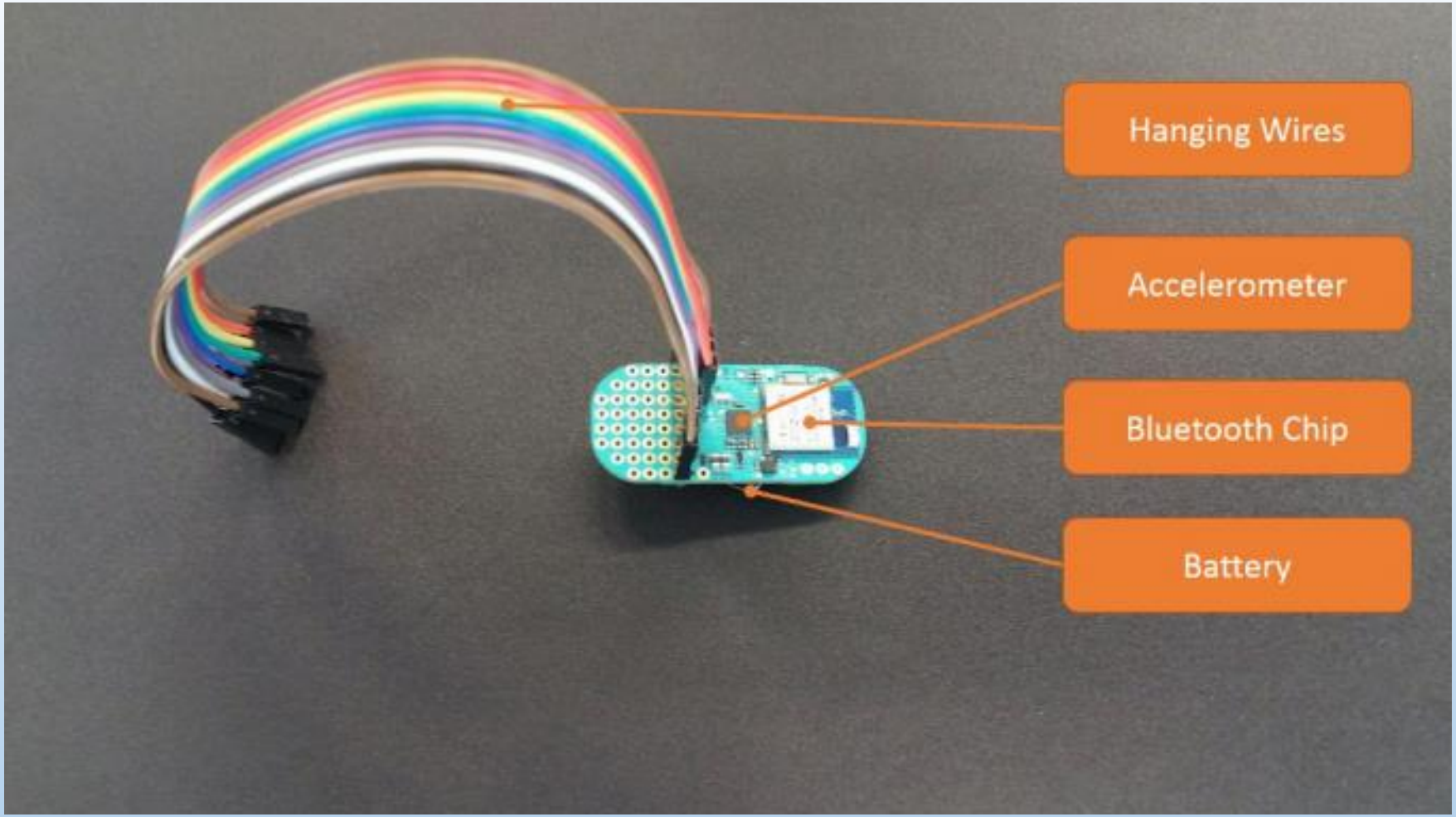

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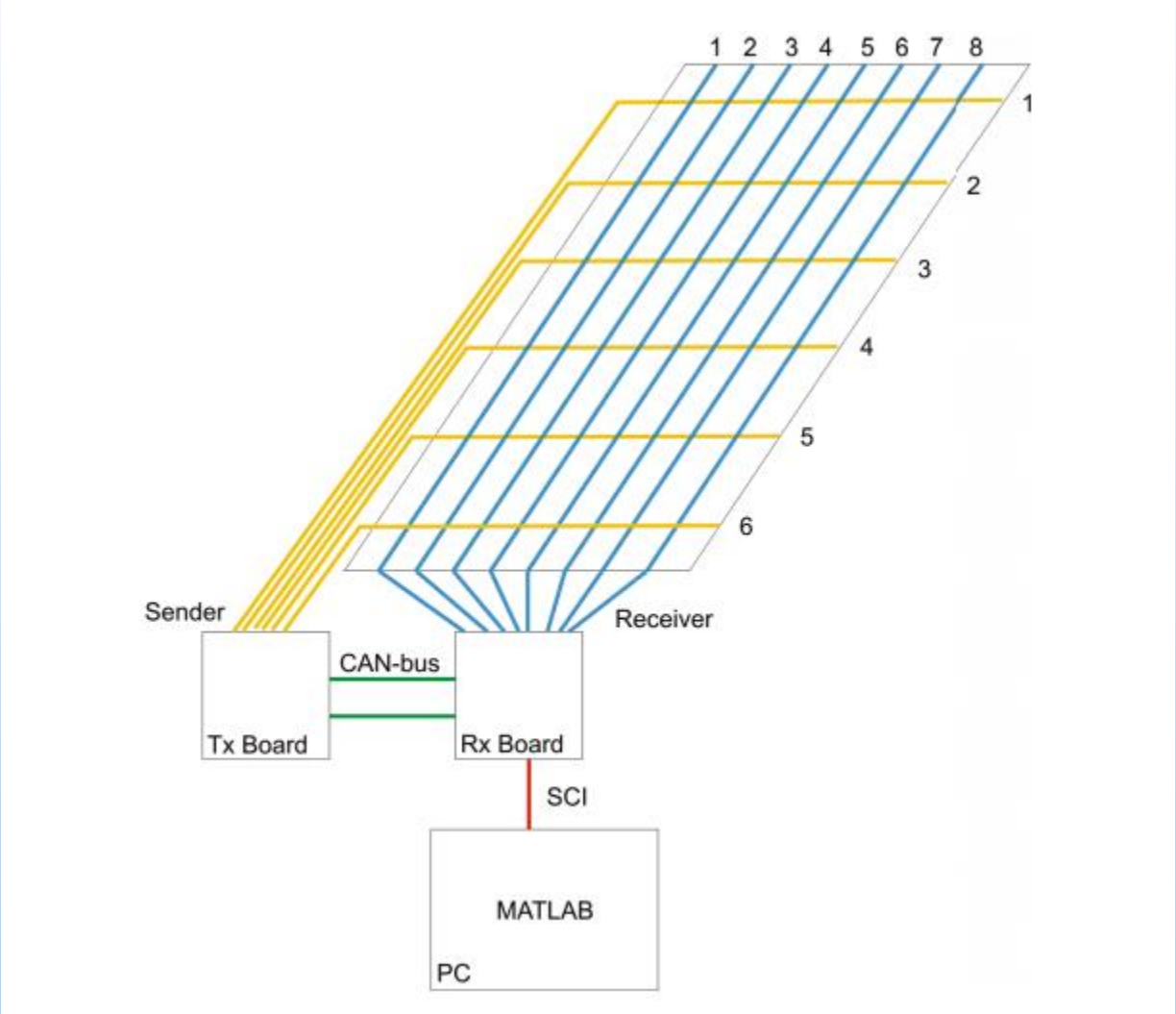
Table 1 Results of evaluations one and two with five different objects and 2-10 users

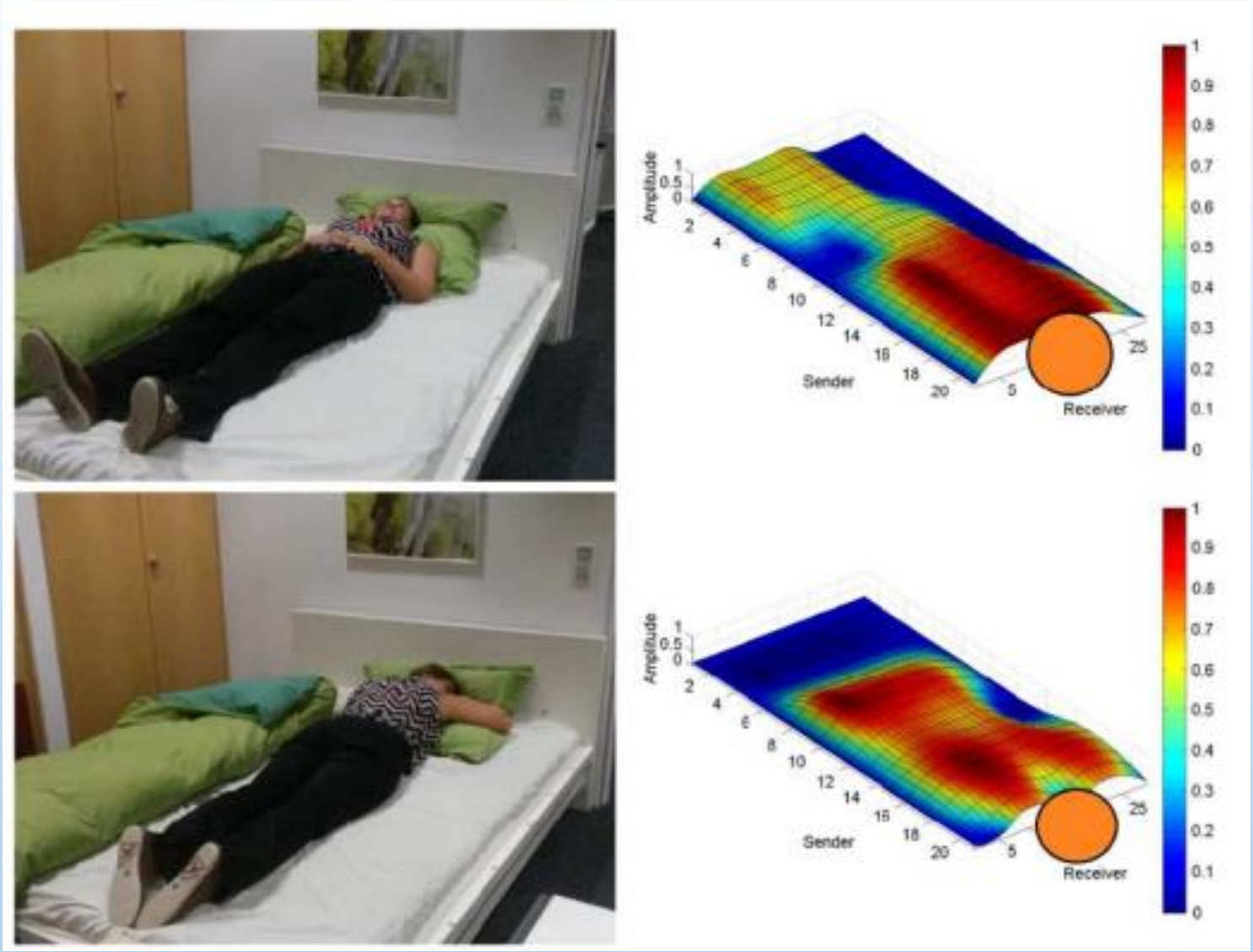
Object	*No. samples*	*Recall Accelerometer*	*Recall Capacitive*
Office chair	20	90%	85%
Wooden chair	20	55%	100%
Wheel chair	20	85%	85%
Bed #1	20	75%	95%
Bed #2	20	50%	90%
Bed #1 (10 users)	200	91%	96%
Bed #2 (10 users)	200	79%	93%

[6] Braun, A., Majewski, M., Wichert, R. and Kuijper, A., 2016, July. Investigating low-cost wireless occupancy sensors for beds. In *International Conference on Distributed, Ambient, and Pervasive Interactions* (pp. 26-34). Springer International Publishing.

Smart Bed



[7] Rus, S., Grosse-Puppendahl, T. and Kuijper, A., 2014, November. Recognition of bed postures using mutual capacitance sensing. In *European Conference on Ambient Intelligence* (pp. 51-66). Springer, Cham.
[8] Rus, S., Grosse-Puppendahl, T. and Kuijper, A., 2017. Evaluating the recognition of bed postures using mutual capacitance sensing. *Journal of Ambient Intelligence and Smart Environments*, *9*(1), pp.113-127.



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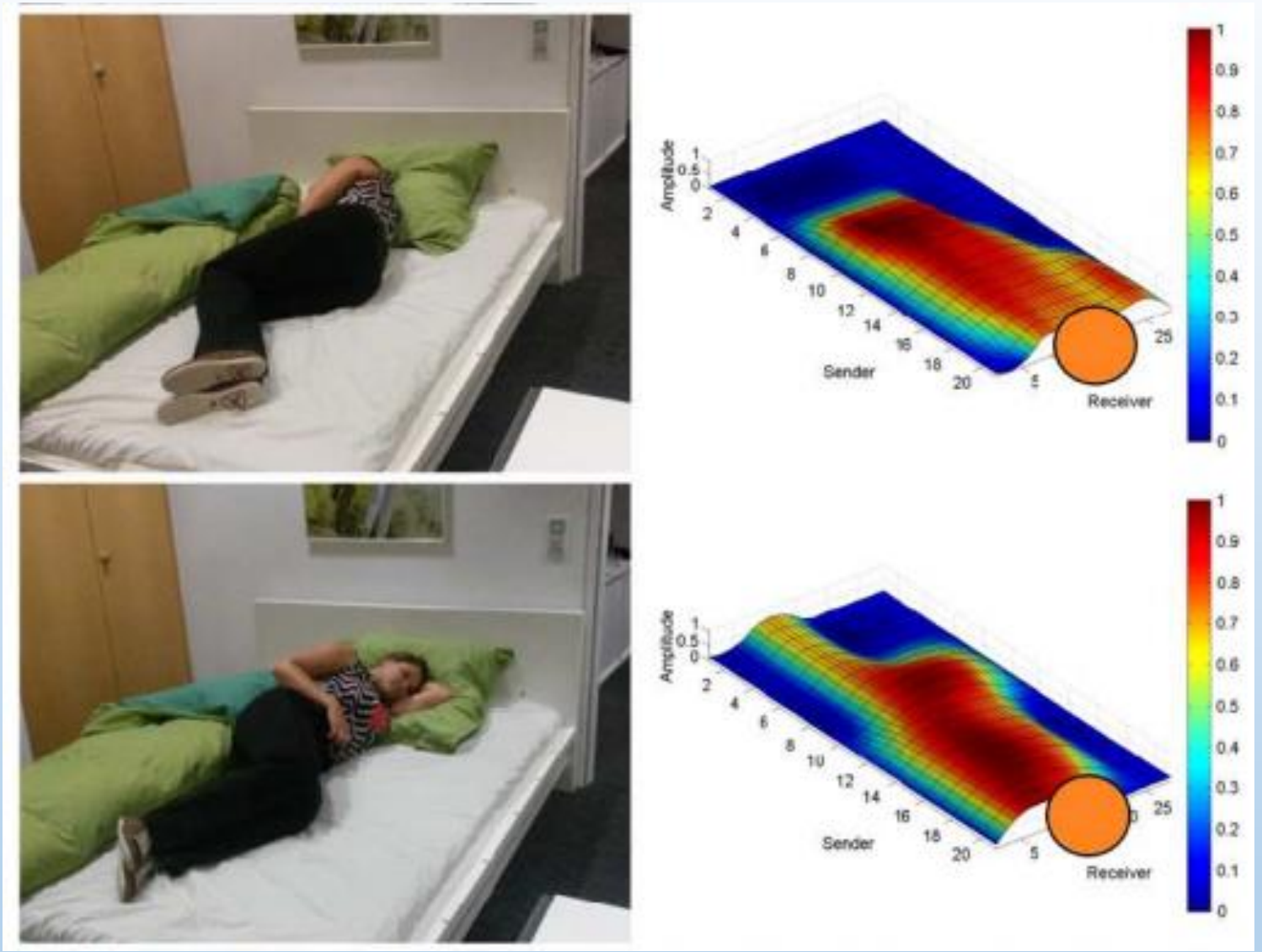

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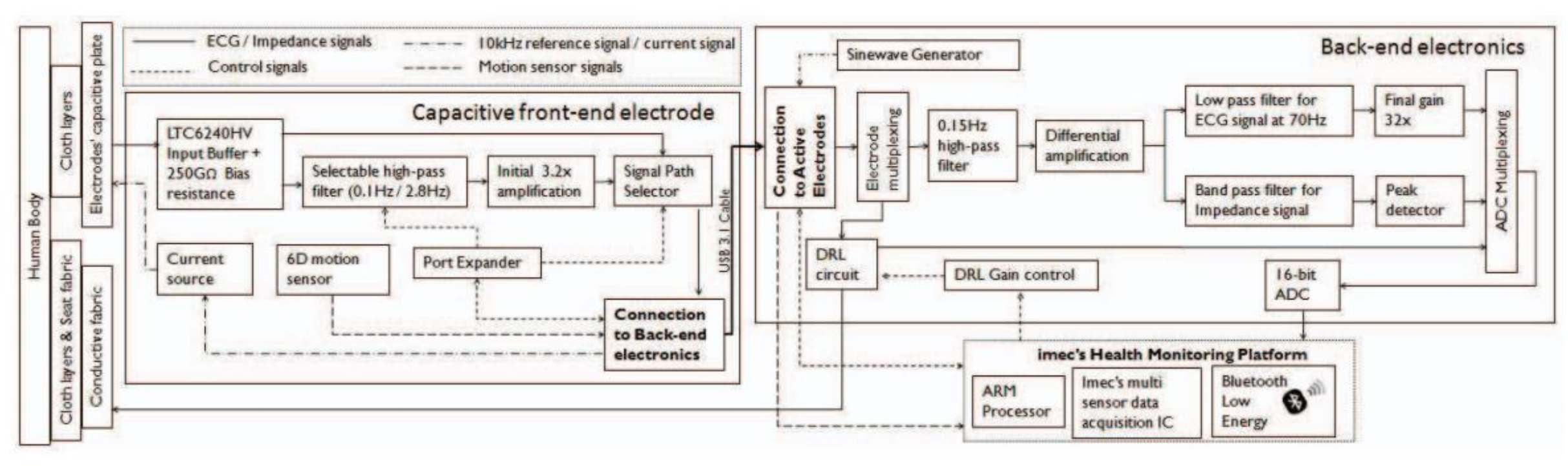
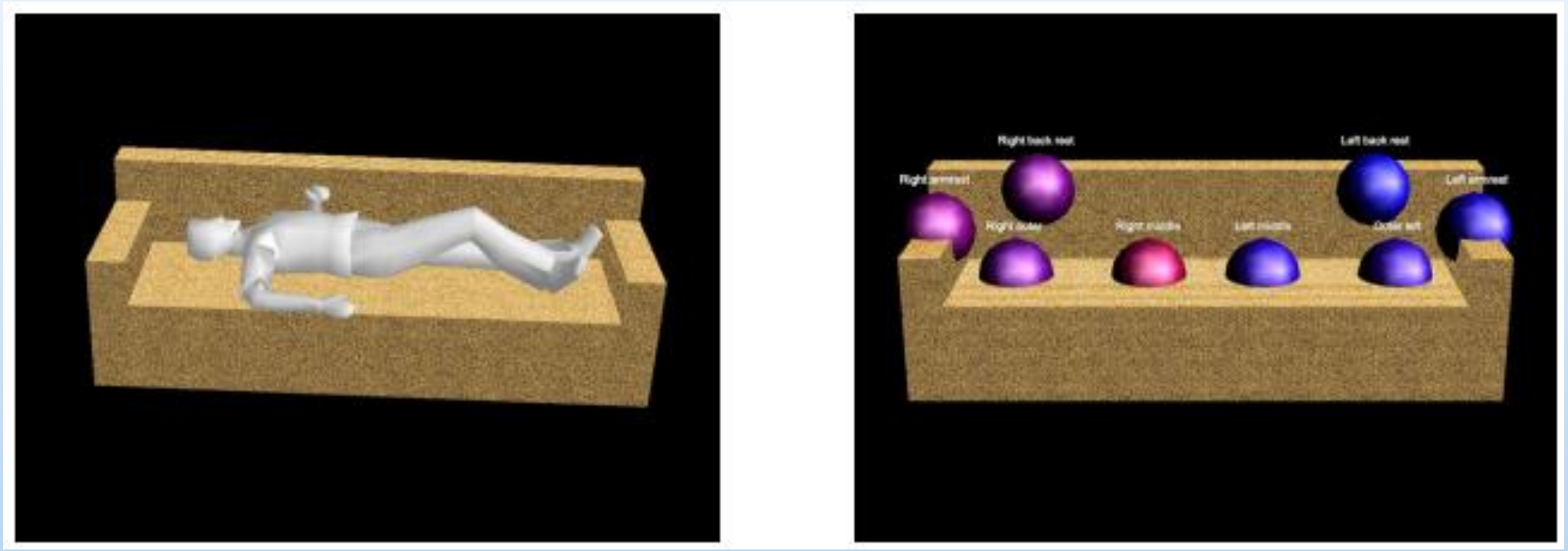


[9] Castro, I.D., Morariu, R., Torfs, T., Van Hoof, C. and Puers, R., 2016, May. Robust wireless capacitive ECG system with adaptive signal quality and motion artifact reduction. In *Medical Measurements and Applications (MeMeA), 2016 IEEE International Symposium on* (pp. 1-6). IEEE.

Smart Chair



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	Naïve Bayes		Decision Trees		RBF network	
Class	Prec	Rec	Prec	Rec	Prec	Rec
sitting outer left one person : OL	0.92	0.97	1.0	0.84	1.0	0.99
sitting middle left one person : ML	0.99	0.60	0.99	0.90	0.98	0.88
sitting outer right one person : OR	1.0	0.78	1.0	0.63	1.0	0.96
sitting middle right one person : MR	0.96	0.93	0.93	1.0	1.0	0.95
lying head right one person : LR	0.77	1.0	1.0	0.89	0.92	1.0
lying head left one person : LL	0.85	1.0	0.7	0.95	0.98	0.99
two persons sitting together : TT	0.77	1.0	0.95	1.0	0.87	1.0
two persons sitting gap : TG	1.0	0.99	0.98	0.64	1.0	0.99
no person : NP	1.0	0.92	0.66	1.00	1.0	1.0
Weighted average	0.92	0.91	0.91	0.87	0.98	0.97

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	OL	ML	OR	MR	LR	LL	TT	TG	NP	Prec	Rec
sitting outer left one person : OL	296	1	0	0	0	2	1	0	0	0.99	0.987
sitting middle left one person : ML	3	227	0	0	0	0	28	0	0	0.983	0.88
sitting outer right one person : OR	0	0	253	0	11	0	0	0	0	1.0	0.958
sitting middle right one person : MR	0	0	0	243	12	0	0	0	0	1.0	0.953
lying head right one person : LR	0	0	0	0	260	0	0	0	0	0.919	1.0
lying head left one person : LL	0	3	0	0	0	254	0	0	0	0.981	0.988
two persons sitting together : TT	0	0	0	0	0	0	197	0	0	0.872	1.0
two persons sitting gap : TG	0	0	0	0	0	3	0	212	0	1.0	0.986
no person : NP	1	0	0	0	0	0	0	0	306	1.0	1.0

Table 2. Confusion matrix for the RBF network classifier

[10] Grosse-Puppendahl, T., Marinc, A. and Braun, A., 2011. Classification of user postures with capacitive proximity sensors in AAL-environments. *Ambient Intelligence*, pp.314-323.

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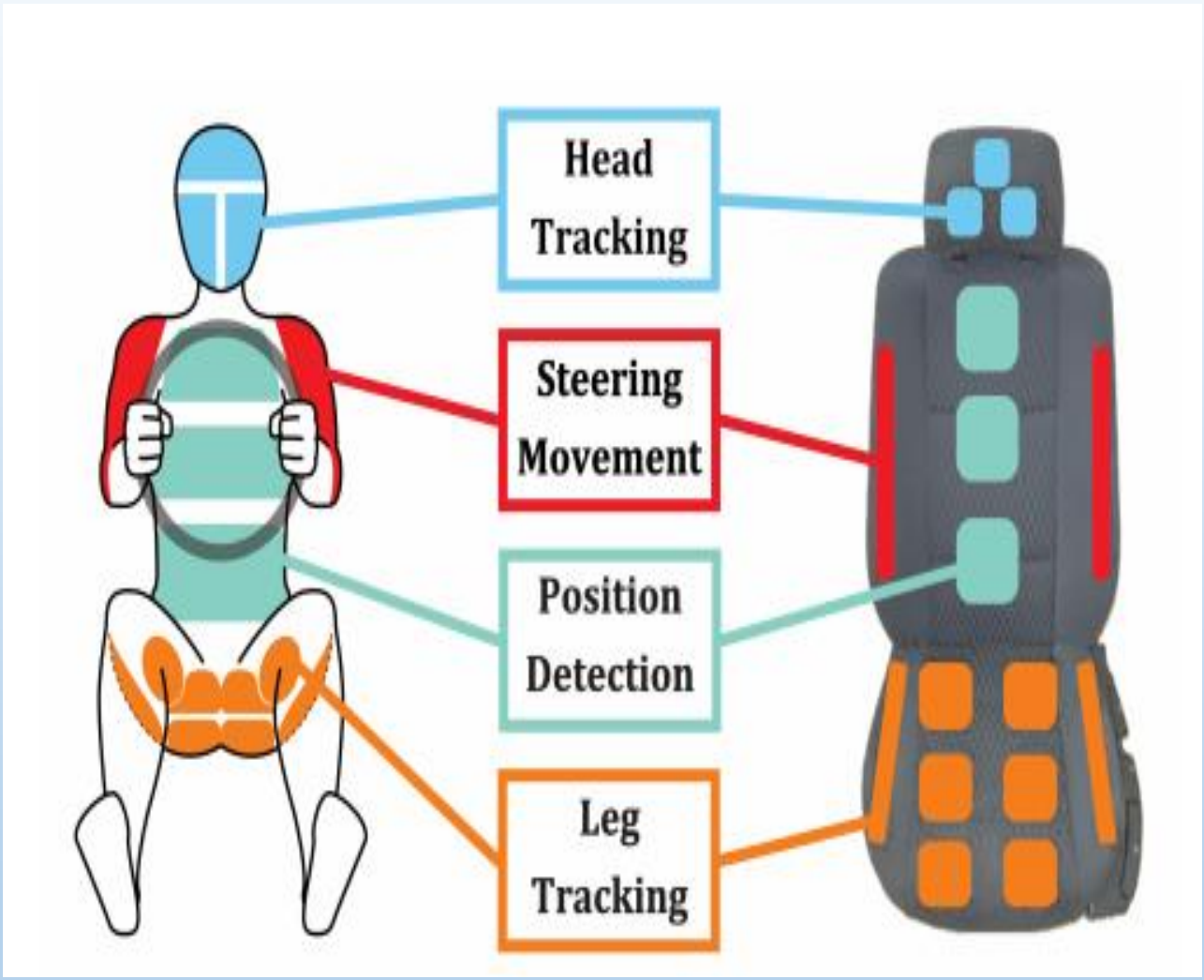

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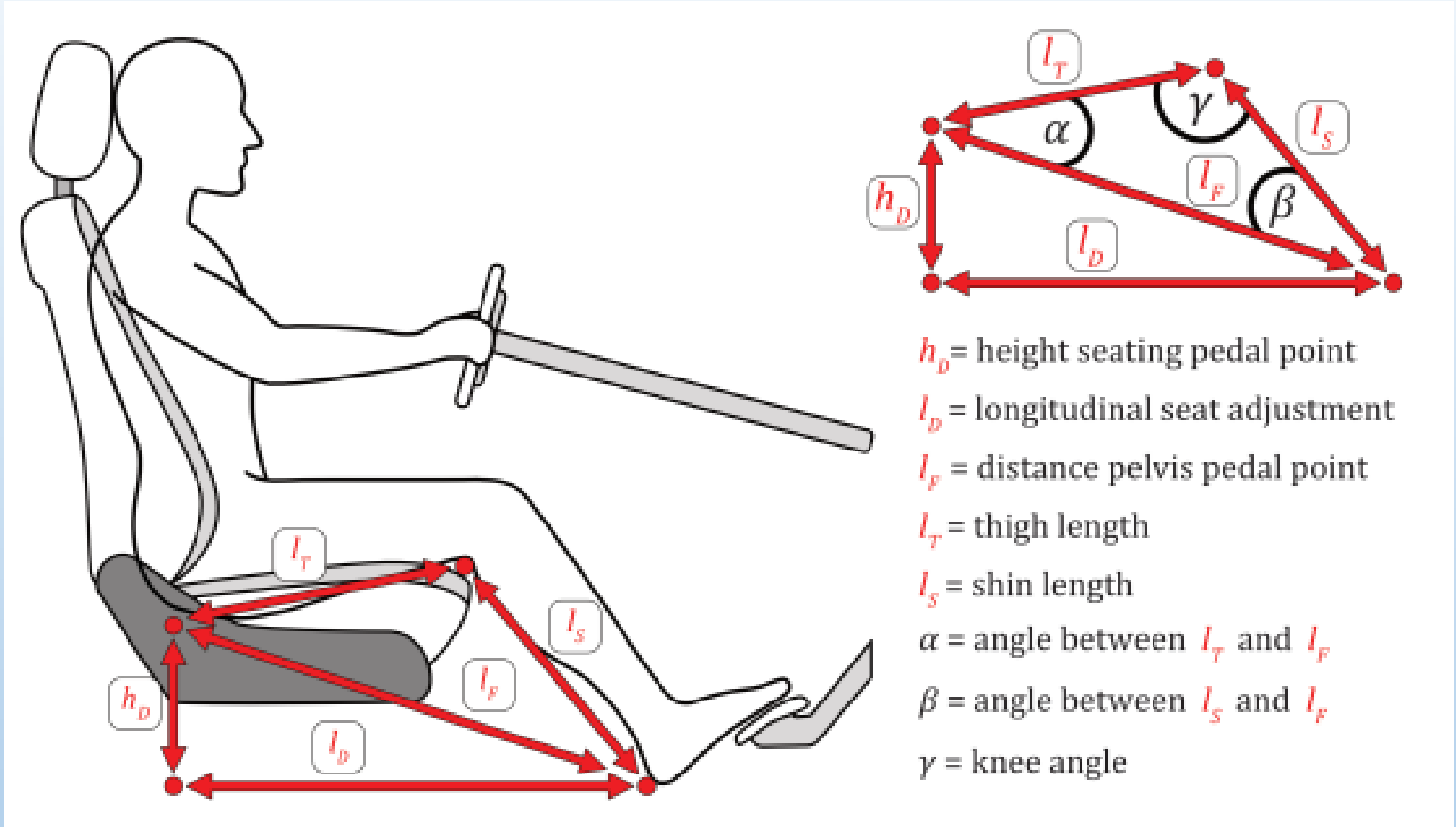

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Table 1. Overview of processing methods of CapSeat

Property	Method	Features	Result
Occupancy	Multiclass SVM	All sensors	Three classes: Empty, foreign object, person
Driver posture	Binary SVM	All sensors	Two classes: Upright, not upright
Head rest adjustment	Multiclass SVM	Three head rest sensors	Three classes: Correct, too low, too high
Seating adjustment	Value ratio	Sensors below knee	Knee angle in degrees
Back rest adjustment	Multiclass SVM	Two pelvis sensors, all back rest sensors	Three classes: Correct, too far back, too far front
Comfort adjustment	Value ratio	Seating sensors, back rest sensors	Balance of proximity distribution
Head posture	Multiclass SVM	Three head rest sensors	Three classes: Correct, whiplash area, airbag zone
Steering velocity	Binary SVM	Back rest sensors - value and derivative	Two classes: Too high, normal
Yawn detection	Binary SVM	Single upper back sensor - frequency spectrum	Two classes: Yawn, breathe
Nod detection	Binary SVM	Three head rest sensors - derivative values over time	Two classes: Nod, no nod
Gaze detection	Multiclass SVM	Three head rest sensors	Six classes: No gaze, down, up, left, right, straight

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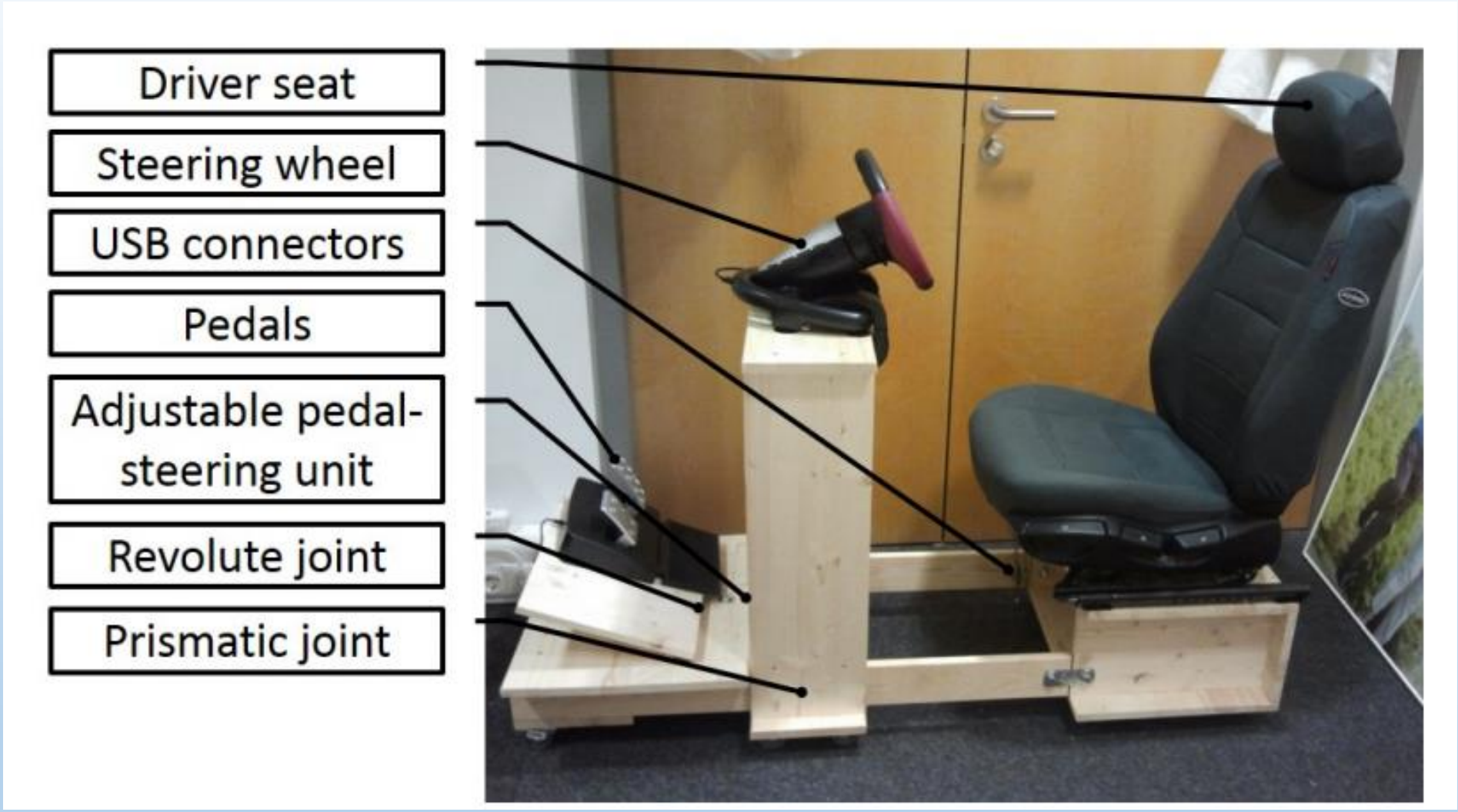


[11] Braun, A., Frank, S., Majewski, M. and Wang, X., 2015, September. CapSeat: capacitive proximity sensing for automotive activity recognition. In *Proceedings of the 7th International Conference on Automotive User Interfaces and Interactive Vehicular Applications* (pp. 225-232). ACM.

[11] Braun, A., Frank, S., Majewski, M. and Wang, X., 2015, September. CapSeat: capacitive proximity sensing for automotive activity recognition. In *Proceedings of the 7th International Conference on Automotive User Interfaces and Interactive Vehicular Applications* (pp. 225-232). ACM.

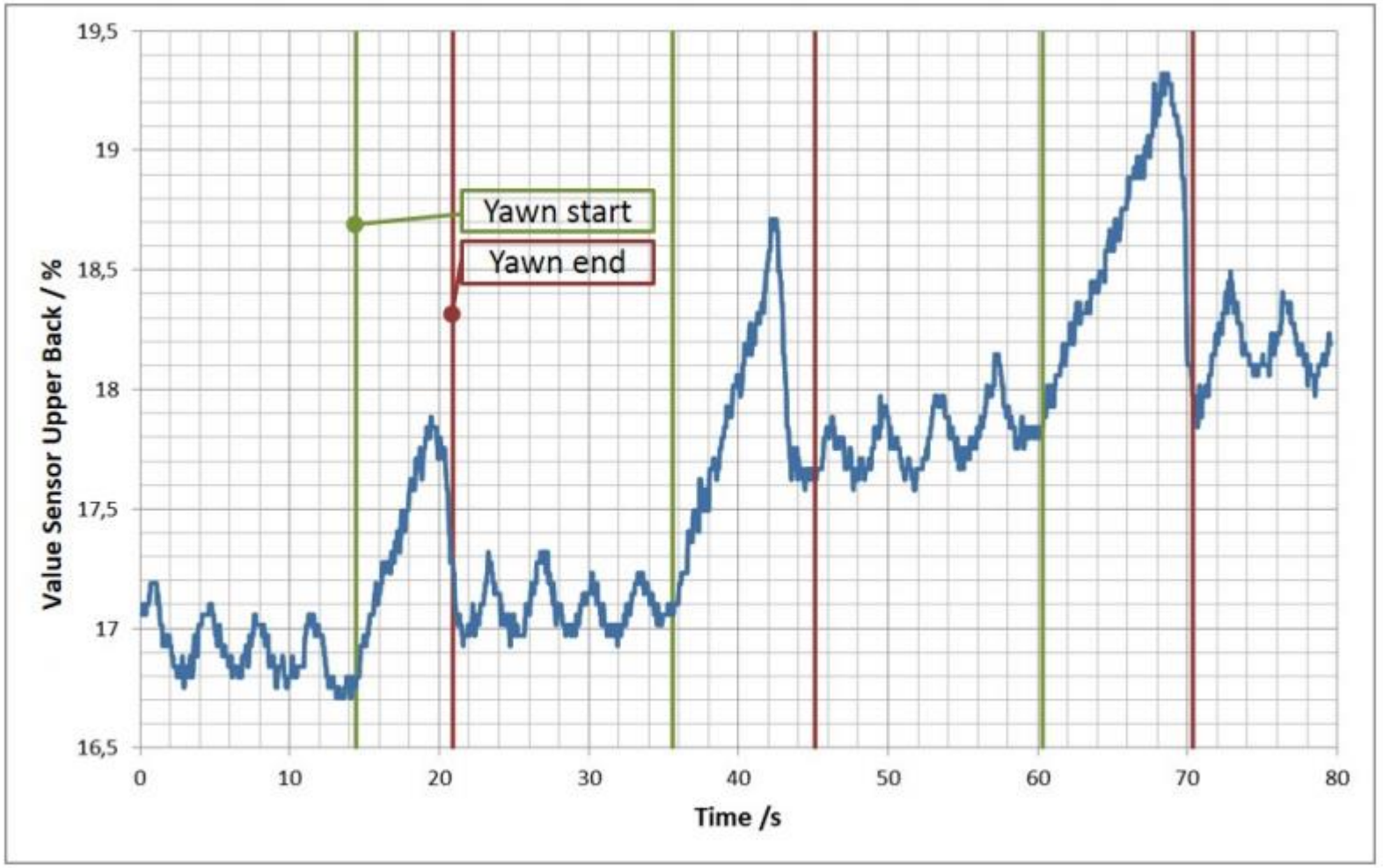


Figure 5. Values of upper back sensor during regular breathing and three yawn events

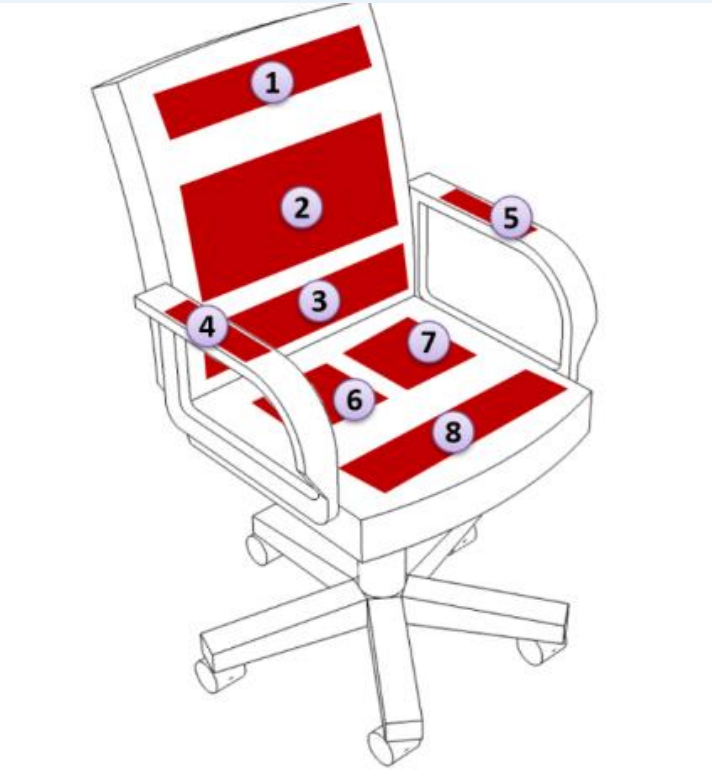
[11] Braun, A., Frank, S., Majewski, M. and Wang, X., 2015, September. CapSeat: capacitive proximity sensing for automotive activity recognition. In *Proceedings of the 7th International Conference on Automotive User Interfaces and Interactive Vehicular Applications* (pp. 225-232). ACM.

[11] Braun, A., Frank, S., Majewski, M. and Wang, X., 2015, September. CapSeat: capacitive proximity sensing for automotive activity recognition. In *Proceedings of the 7th International Conference on Automotive User Interfaces and Interactive Vehicular Applications* (pp. 225-232). ACM.

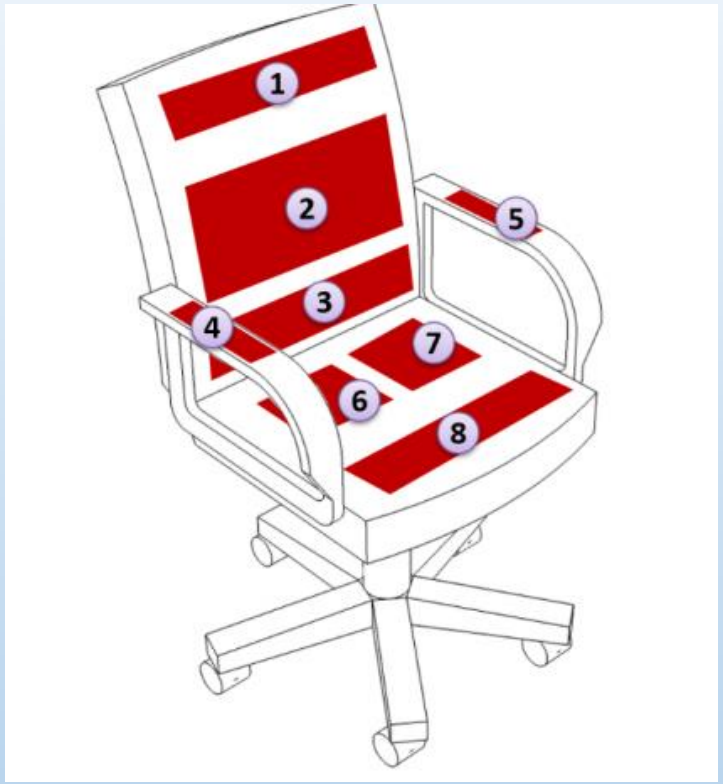
Table 2. Classification results

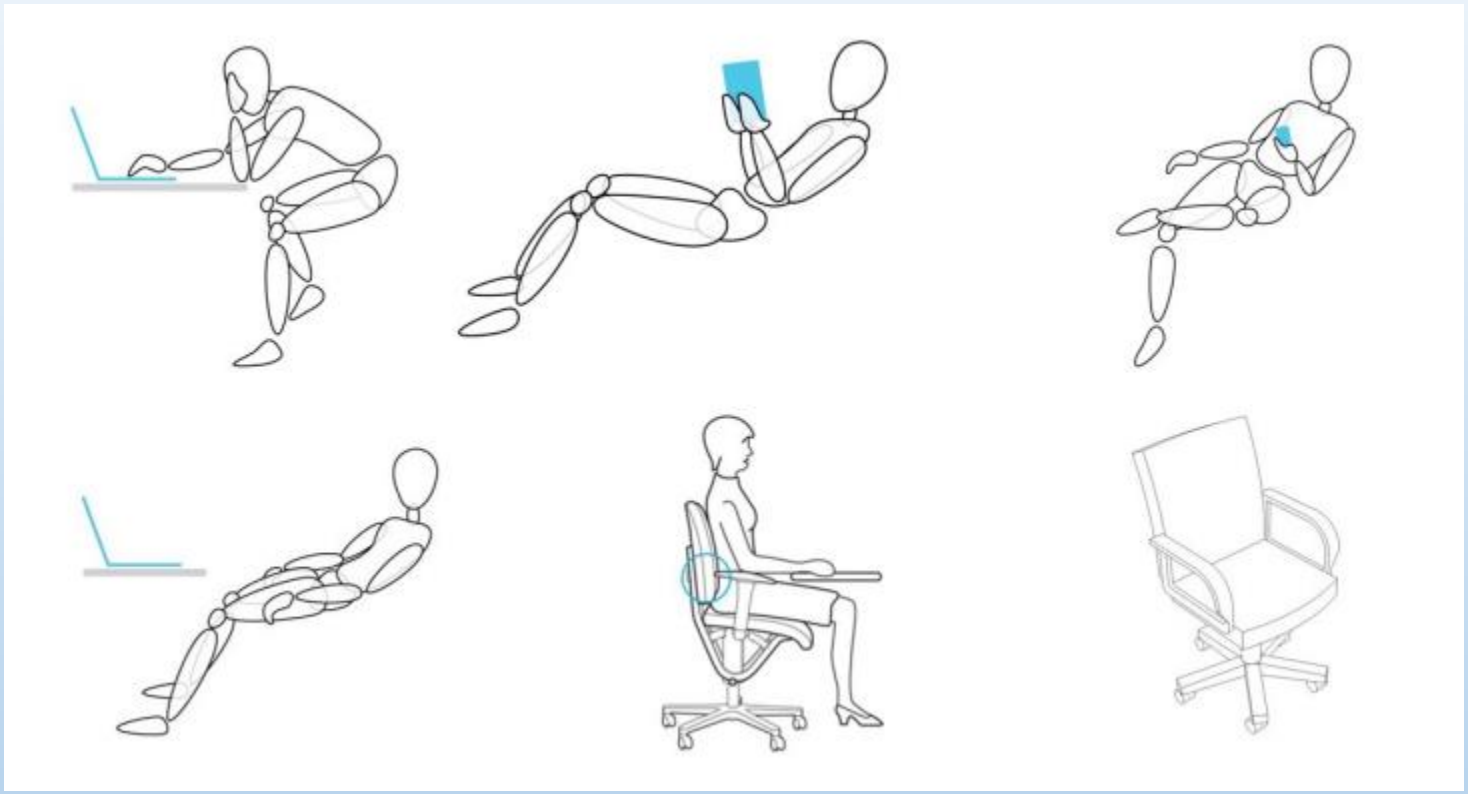
Property	# samples	Rate
Occupancy	2522	100.00%
Driver posture	2682	95.26%
Back rest adjustment	885	99.80%
Head rest adjustment	410	94.15%
Head rest (modified features)	410	100.00%
Steering velocity	2596	97.50%
Yawn detection	103	100.00%
Nod detection	372	95.20%
Gaze detection	1604	99.69%
Longitudinal adjustment	*1732*	*100.00%*

[11] Braun, A., Frank, S., Majewski, M. and Wang, X., 2015, September. CapSeat: capacitive proximity sensing for automotive activity recognition. In *Proceedings of the 7th International Conference on Automotive User Interfaces and Interactive Vehicular Applications* (pp. 225-232). ACM.



[12] Braun, A., Frank, S. and Wichert, R., 2015, August. The capacitive chair. In *International Conference on Distributed, Ambient, and Pervasive Interactions* (pp. 397-407). Springer, Cham.





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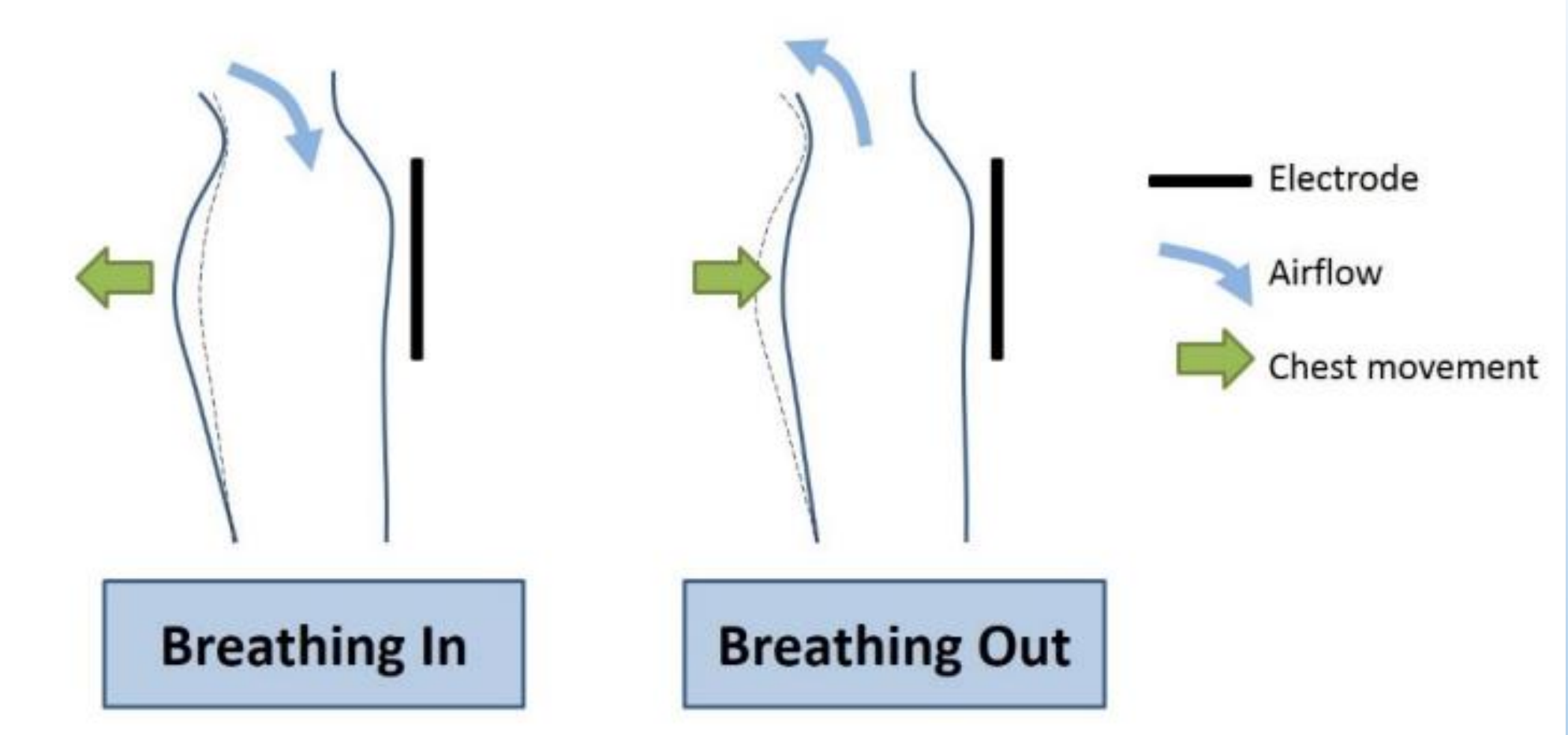

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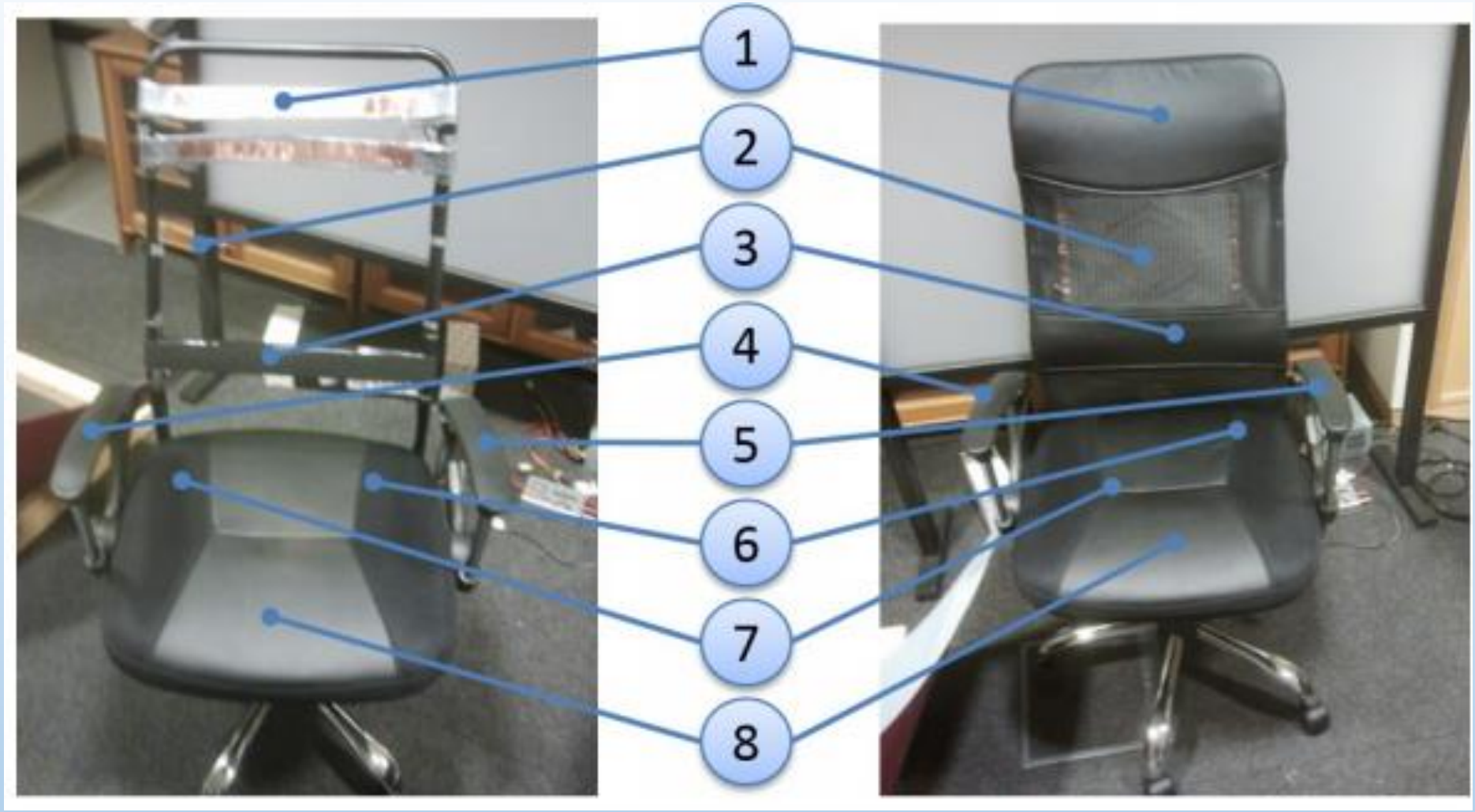

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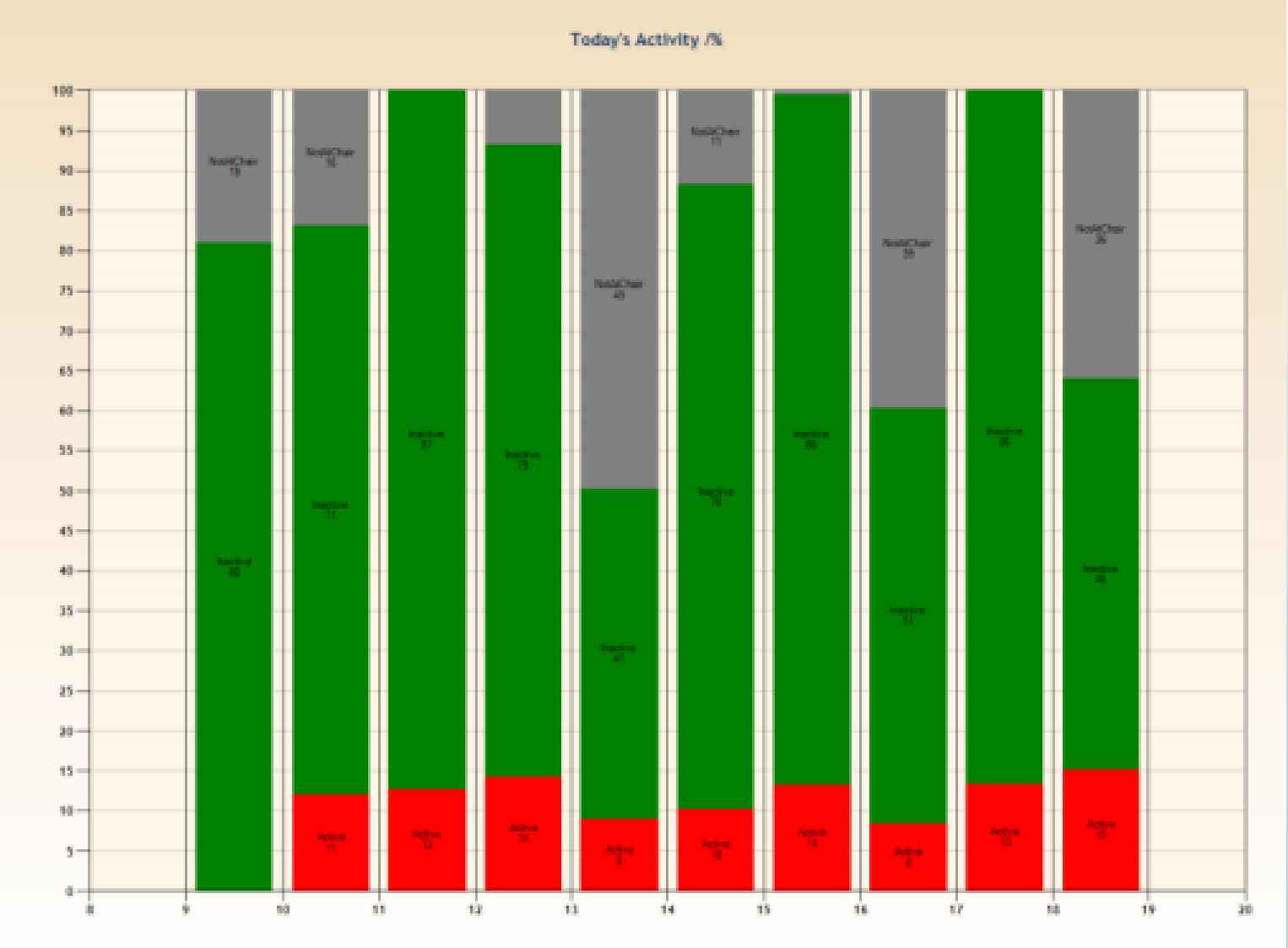


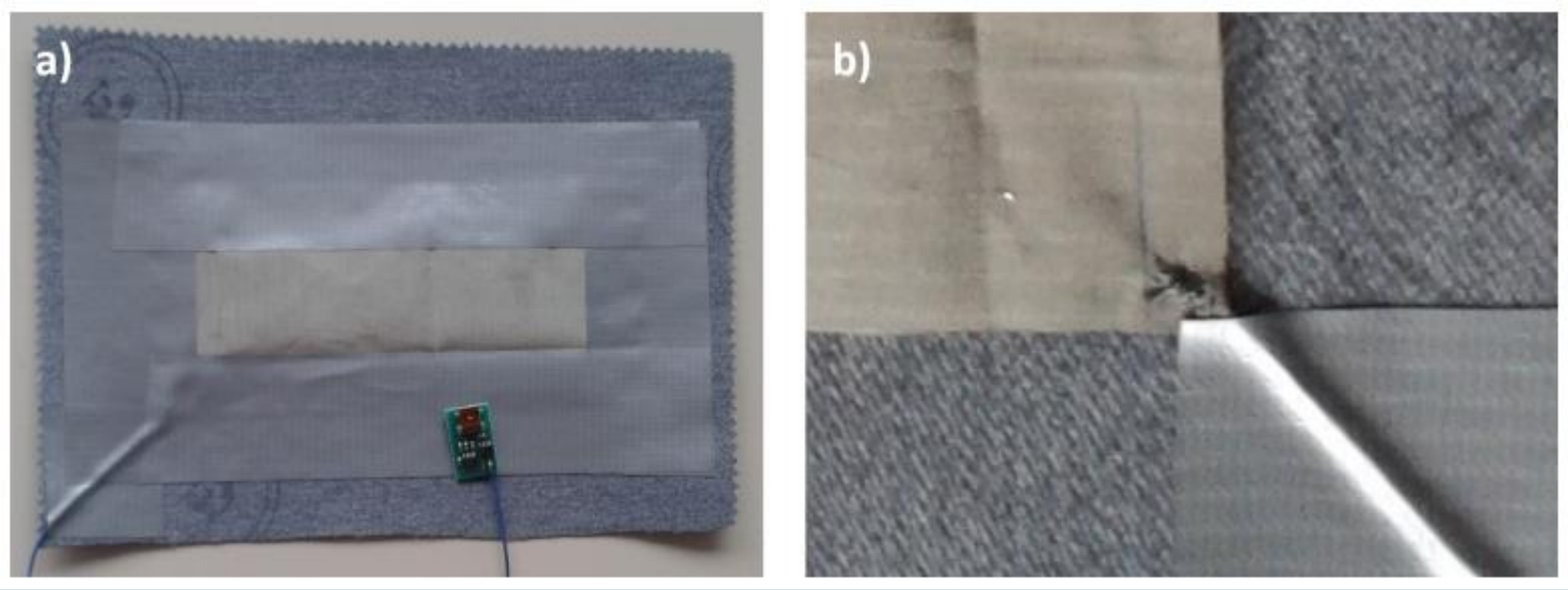
[12] Braun, A., Frank, S. and Wichert, R., 2015, August. The capacitive chair. In *International Conference on Distributed, Ambient, and Pervasive Interactions* (pp. 397-407). Springer, Cham.

Table 1. Results of posture recognition test in percent

	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	Avg
Upright	100	100	100	100	100	100	100	100	100	100	**100**
The Strunch	100	100	100	100	86	100	100	100	100	100	**98,6**
Take it in	100	100	100	100	100	100	100	100	55	100	**95,5**
Close to chair	100	100	100	100	100	100	100	100	100	100	**100**

[12] Braun, A., Frank, S. and Wichert, R., 2015, August. The capacitive chair. In *International Conference on Distributed, Ambient, and Pervasive Interactions* (pp. 397-407). Springer, Cham.

[13] Rus, S., Braun, A. and Kuijper, A., 2017, April. E-Textile Couch: Towards Smart Garments Integrated Furniture. In *European Conference on Ambient Intelligence* (pp. 214-224). Springer, Cham.



[13] Rus, S., Braun, A. and Kuijper, A., 2017, April. E-Textile Couch: Towards Smart Garments Integrated Furniture. In *European Conference on Ambient Intelligence* (pp. 214-224). Springer, Cham.

- **Class 1** Empty couch
- **Class 2** Sitting upright, on right side
- **Class 3** Sitting on edge, on right side
- **Class 4** Sitting leaned back, on right side
- **Class 5** Sitting upright, on right side, using armrest in front
- **Class 6** Sitting leaned back, on right side, using armrest in front
- **Class 7** Sitting leaned back, on right side, using armrest at back
- **Class 8** Sitting upright, in the middle
- **Class 9** Sitting on edge, in the middle
- **Class 10** Sitting leaned back, in the middle
- **Class 11** Sitting upright, on left side
- **Class 12** Sitting on edge, on left side
- **Class 13** Sitting leaned back, on left side
- **Class 14** Lying down, head on right side
- **Class 15** Lying down, head on left side

[13] Rus, S., Braun, A. and Kuijper, A., 2017, April. E-Textile Couch: Towards Smart Garments Integrated Furniture. In *European Conference on Ambient Intelligence* (pp. 214-224). Springer, Cham.

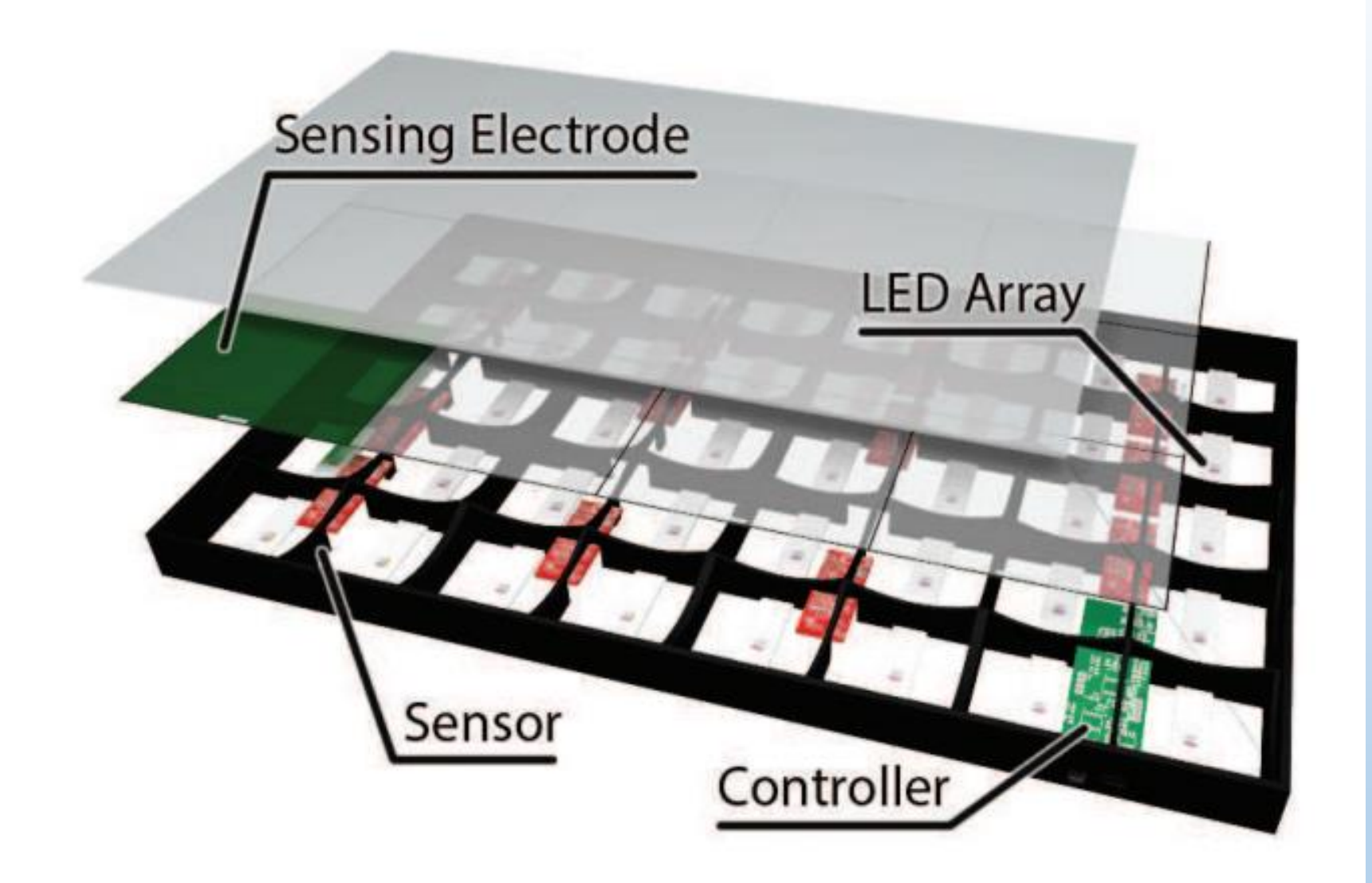
Fig. 3. a) Sitting upright; b) Sitting upright using armrest in front; c) Sitting leaned back using armrest in front; d) Sitting leaned back using armrest at back;

[13] Rus, S., Braun, A. and Kuijper, A., 2017, April. E-Textile Couch: Towards Smart Garments Integrated Furniture. In *European Conference on Ambient Intelligence* (pp. 214-224). Springer, Cham.

Data	C4.5 decision tree		kNN		Naive Bayes		SVM	
	Acc.[%]	F-m.[%]	Acc.[%]	F-m.[%]	Acc.[%]	F-m.[%]	Acc.[%]	F-m.[%]
Raw	82.3	77.0	80.7	75.6	84.0	79.8	85.7	81.9
Normalized	89.1	86.0	88.9	86.2	87.2	84.1	**91.2**	**88.8**
Subset raw	83.3	78.9	87.5	83.9	89.7	87.0	90.45	88.1
Subset normalized	89.9	87.2	91.6	88.9	95.3	94.1	**95.5**	**94.1**

[13] Rus, S., Braun, A. and Kuijper, A., 2017, April. E-Textile Couch: Towards Smart Garments Integrated Furniture. In *European Conference on Ambient Intelligence* (pp. 214-224). Springer, Cham.

Smart Surface



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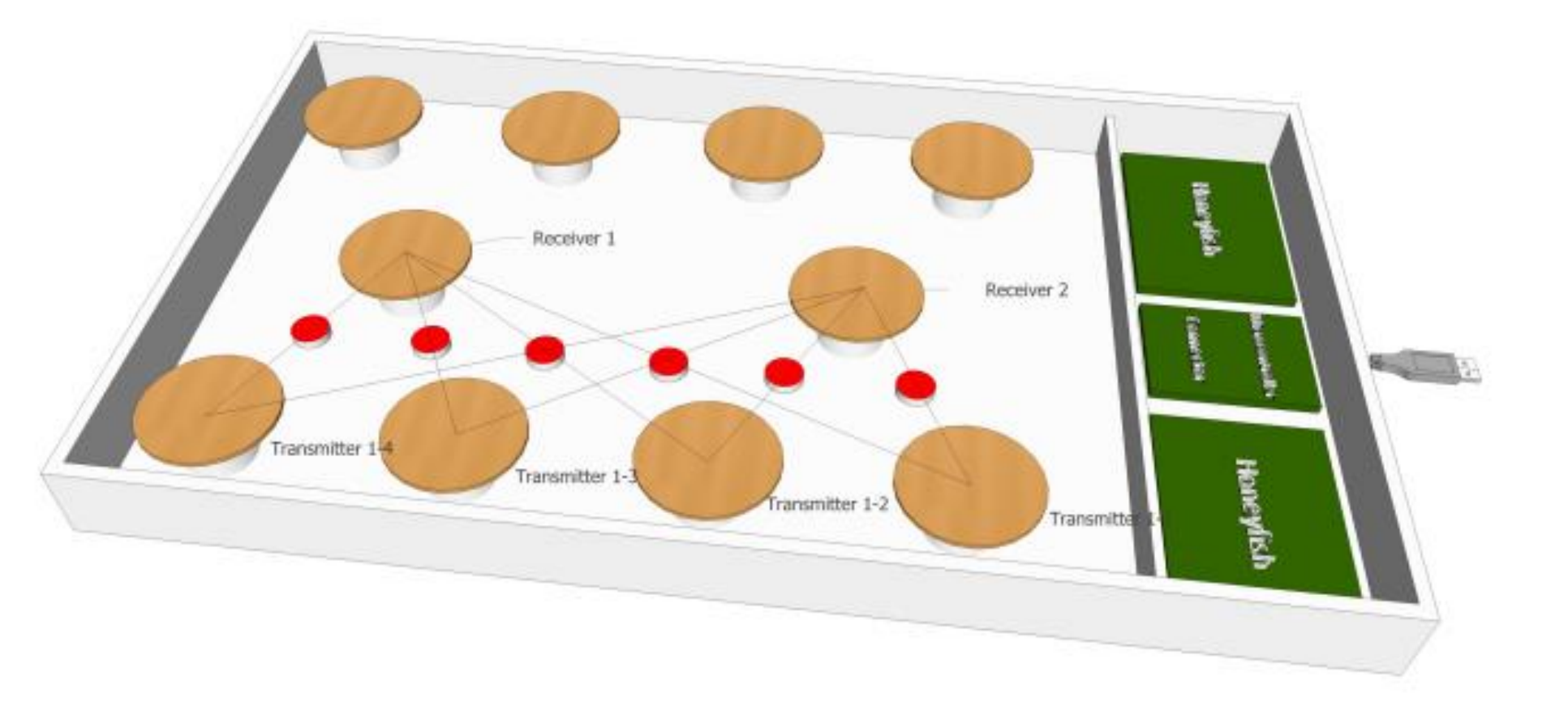


[15] Grosse-Puppendahl, T. and Braun, A., 2012. Honeyfish-a high resolution gesture recognition system based on capacitive proximity sensing. In *Embedded World Conference* (Vol. 12).

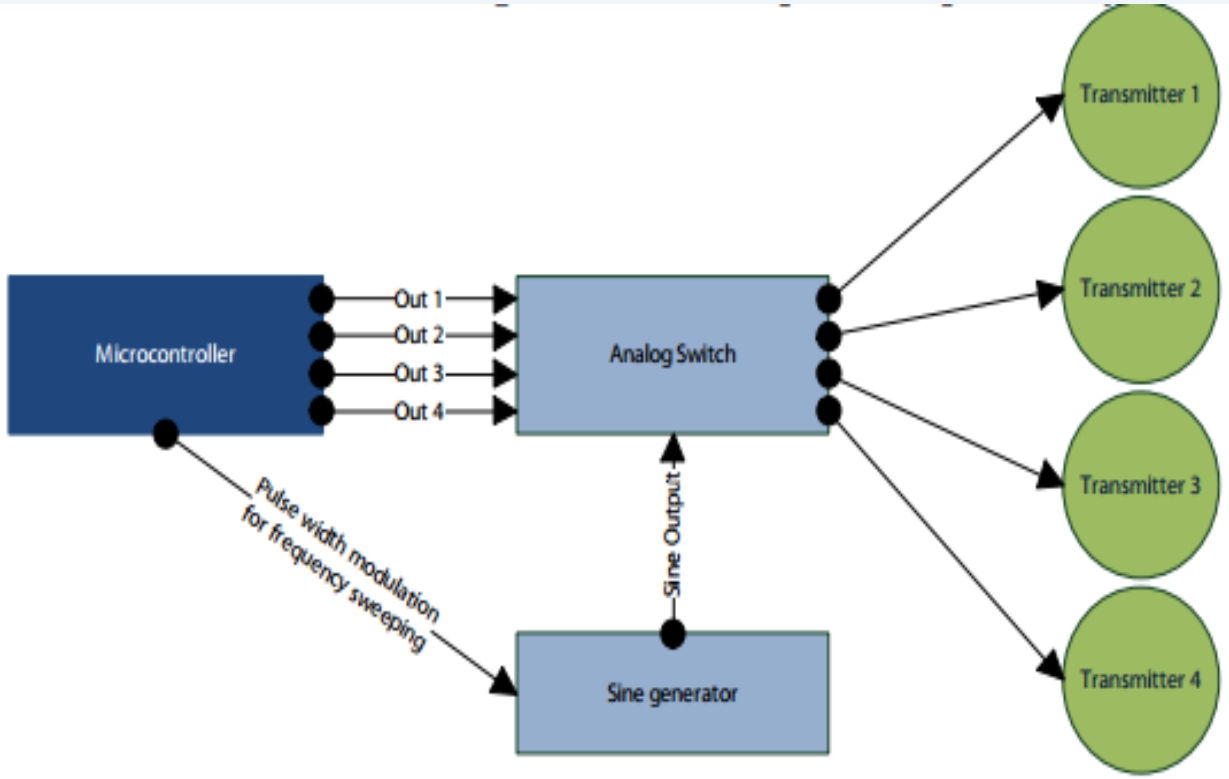


Fig. 6. Block diagram of the transmitter

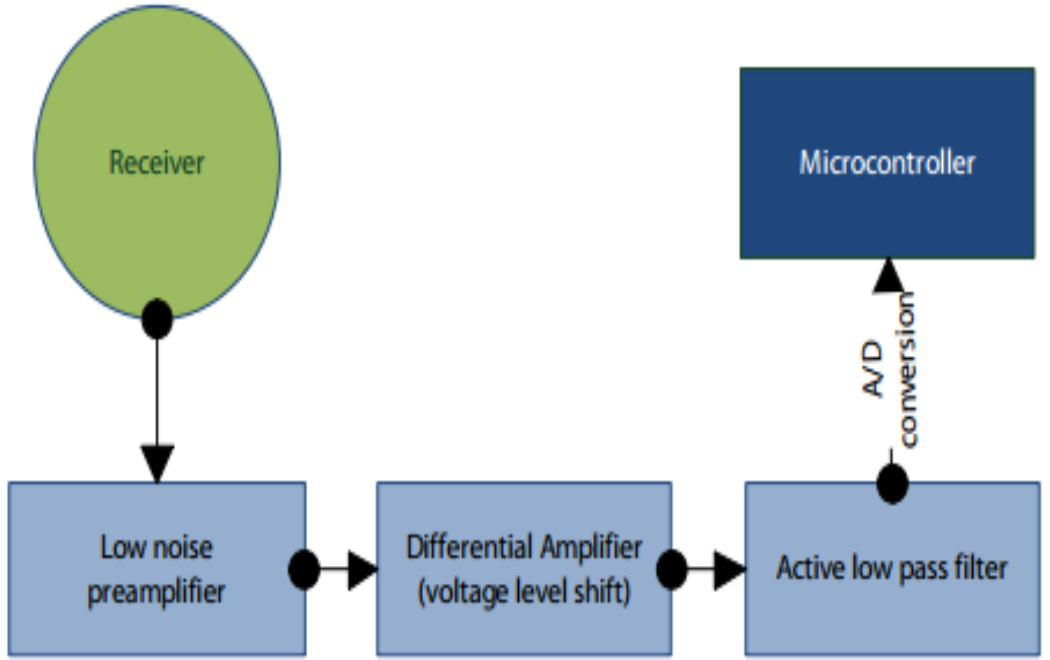
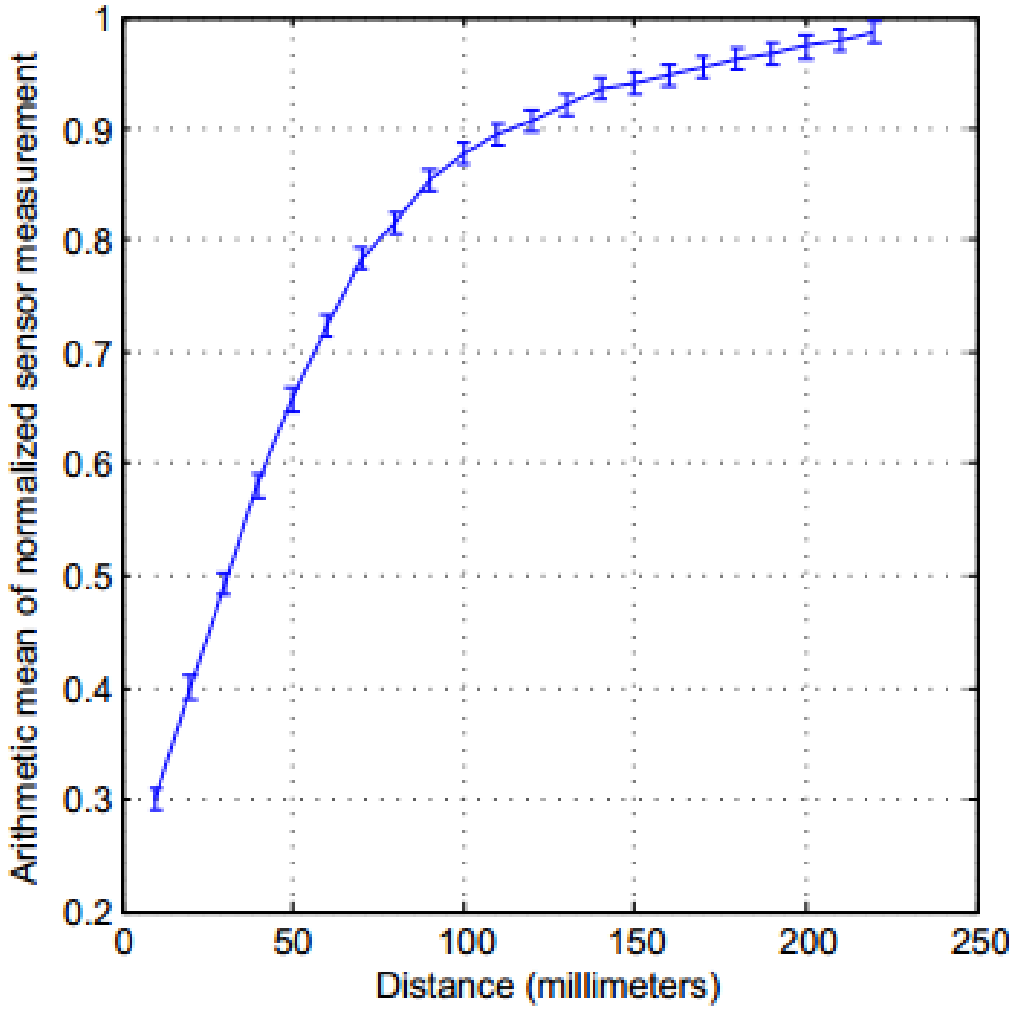
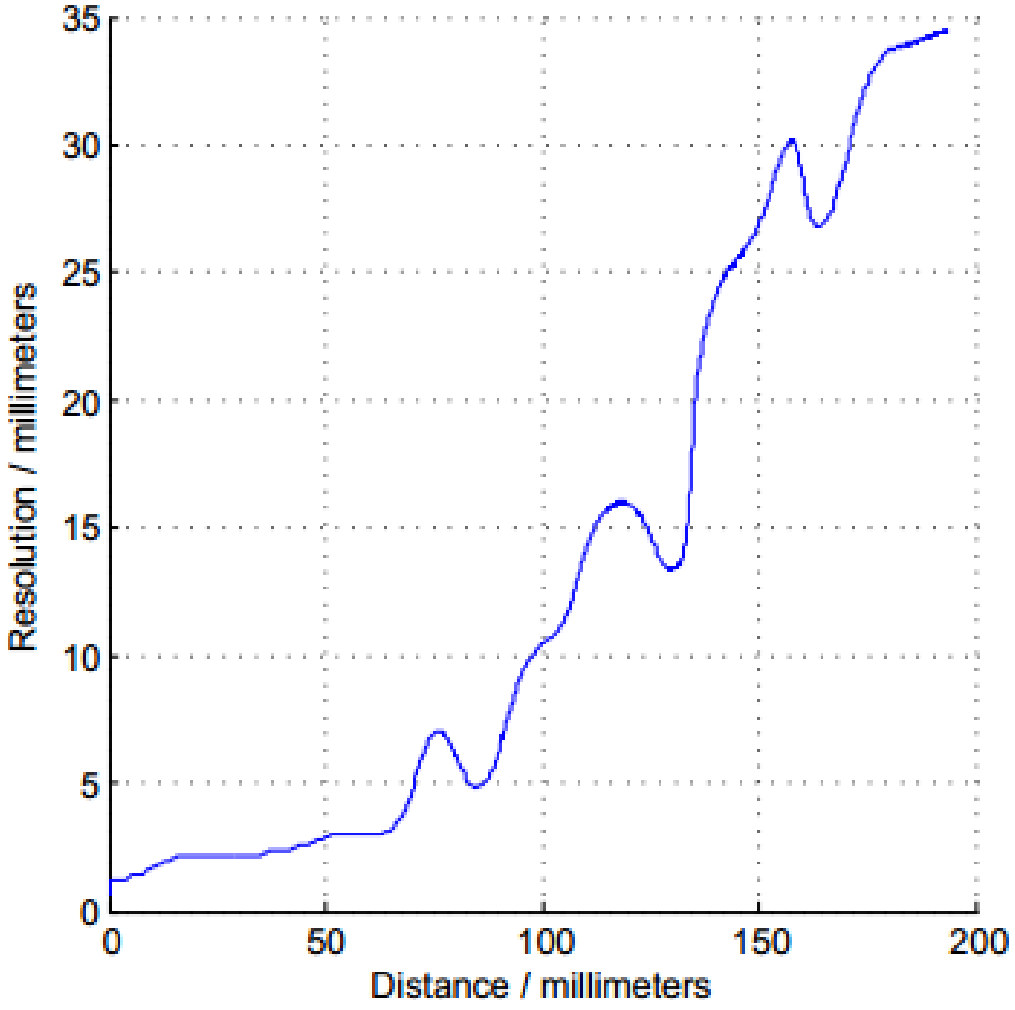


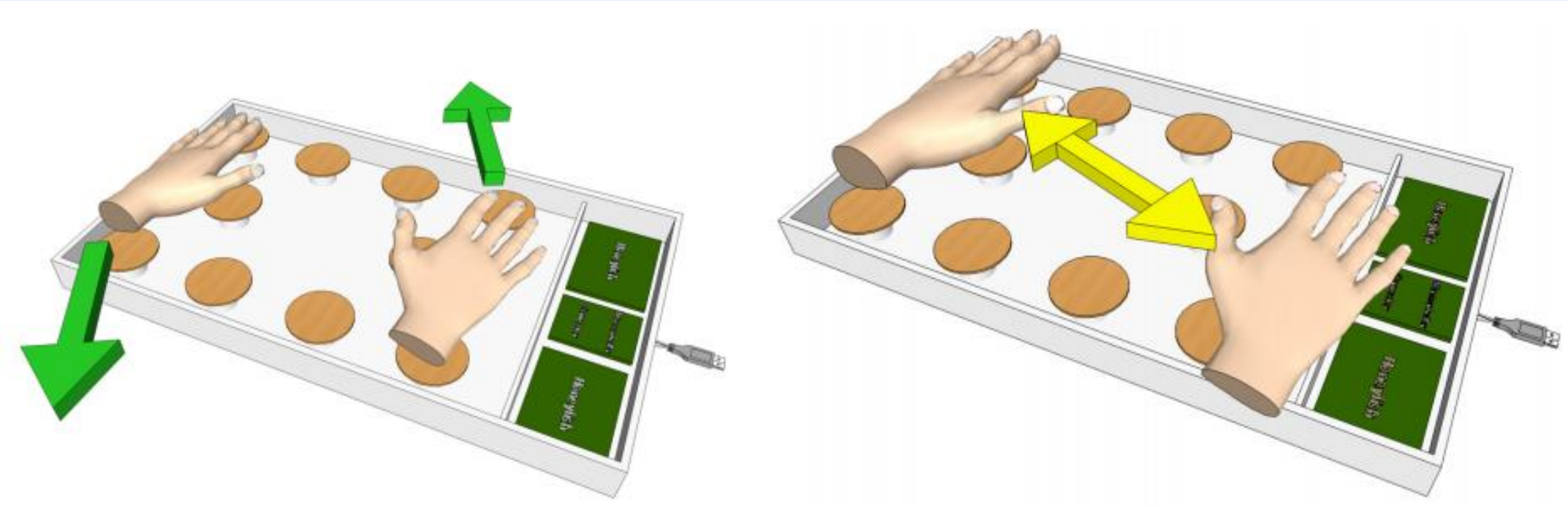
Fig. 7. Block diagram of the receiver circuit

[15] Grosse-Puppendahl, T. and Braun, A., 2012. Honeyfish-a high resolution gesture recognition system based on capacitive proximity sensing. In *Embedded World Conference* (Vol. 12).

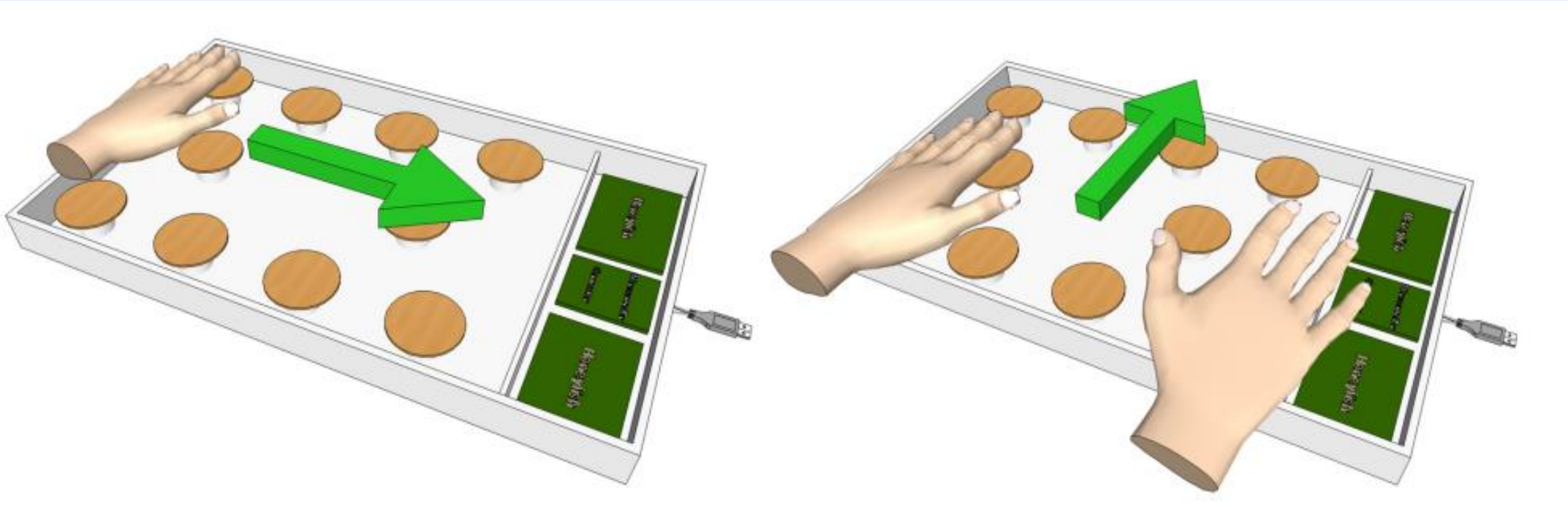




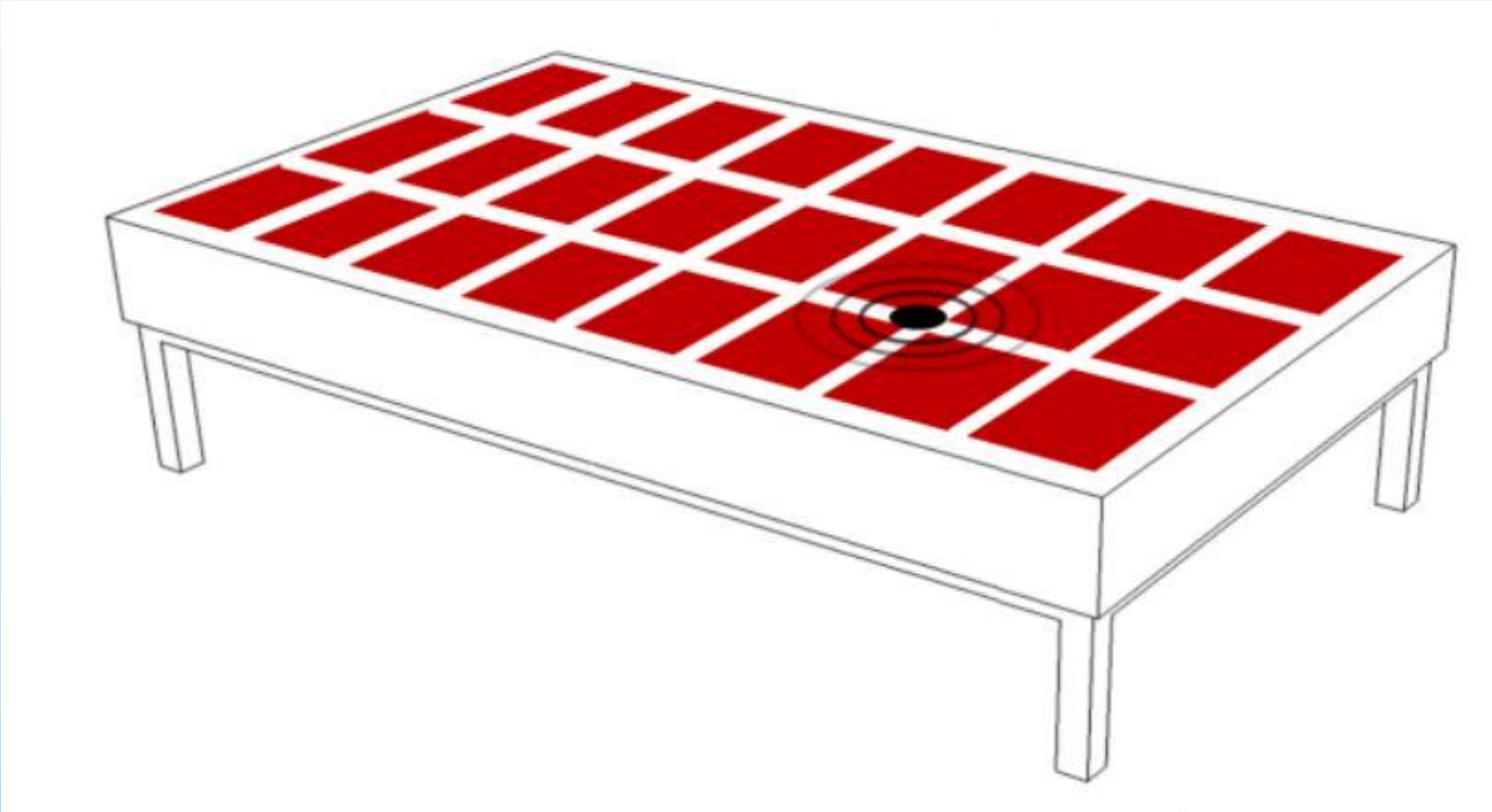
[15] Grosse-Puppendahl, T. and Braun, A., 2012. Honeyfish-a high resolution gesture recognition system based on capacitive proximity sensing. In *Embedded World Conference* (Vol. 12).

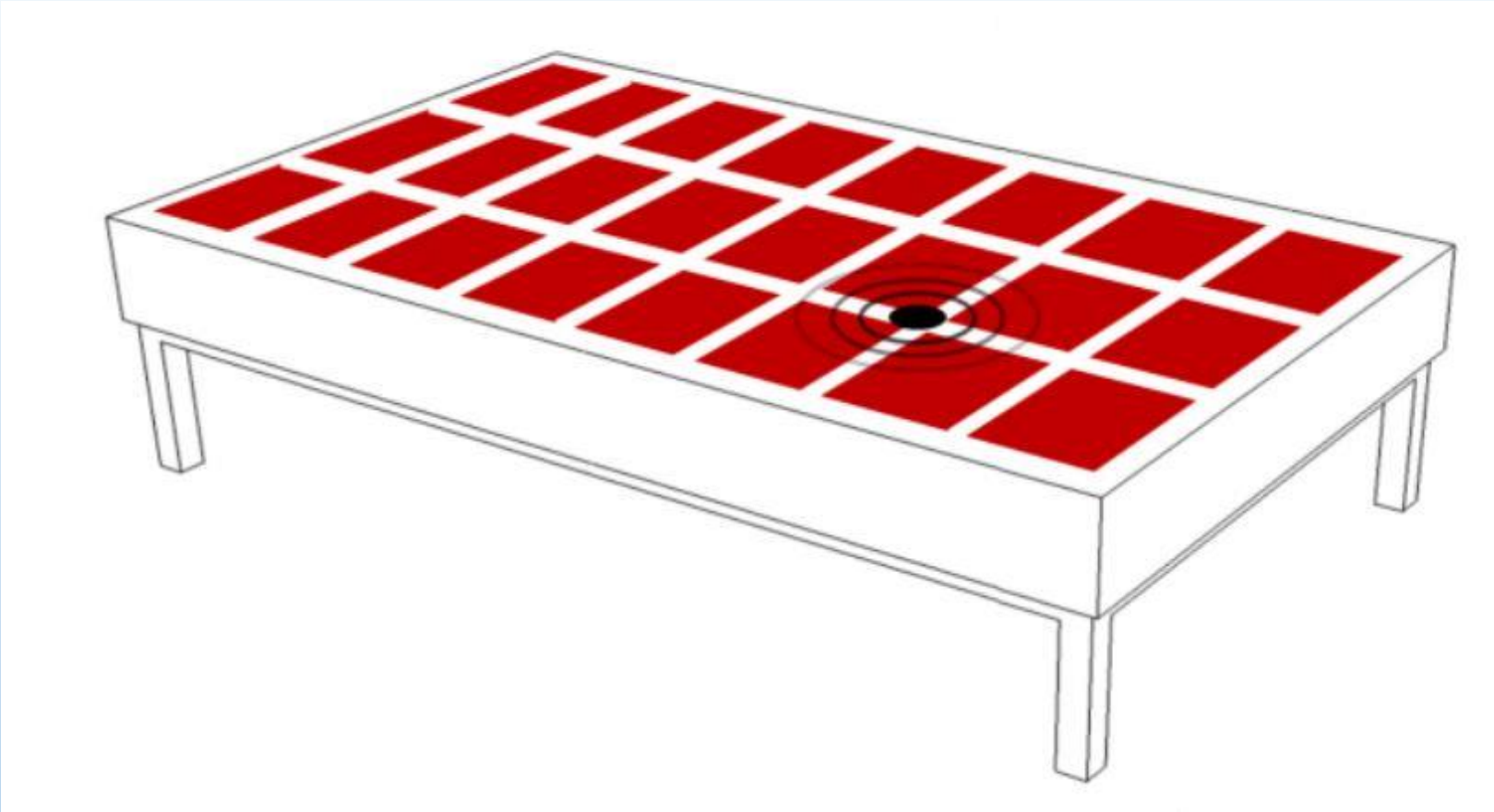


[16] Grosse-Puppendahl, T., Braun, A., Kamieth, F. and Kuijper, A., 2013, April. Swiss-cheese extended: an object recognition method for ubiquitous interfaces based on capacitive proximity sensing. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (pp. 1401-1410). ACM.

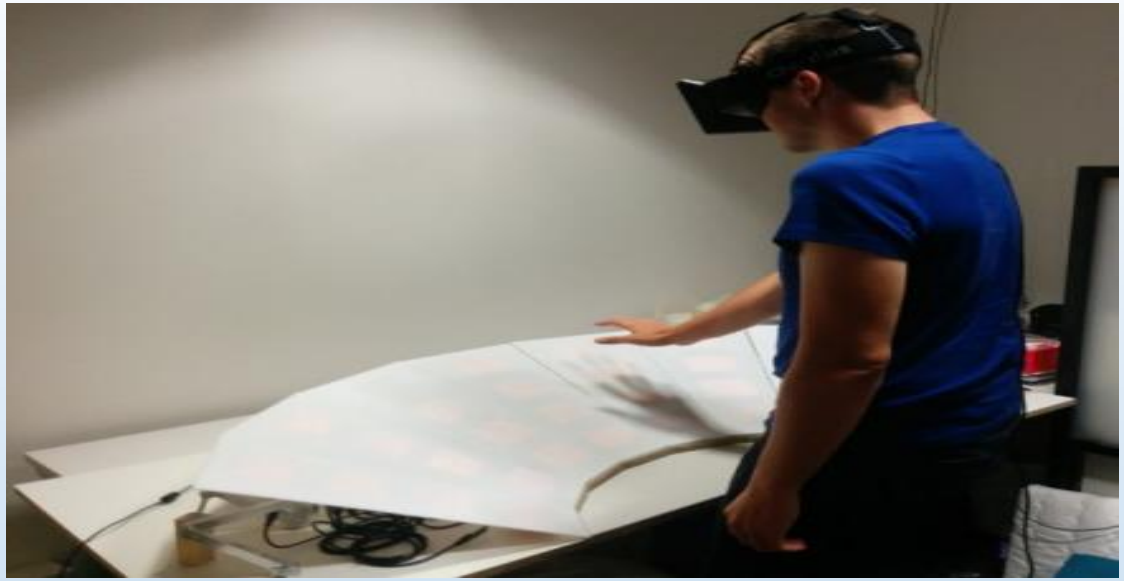


[16] Grosse-Puppendahl, T., Braun, A., Kamieth, F. and Kuijper, A., 2013, April. Swiss-cheese extended: an object recognition method for ubiquitous interfaces based on capacitive proximity sensing. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (pp. 1401-1410). ACM.

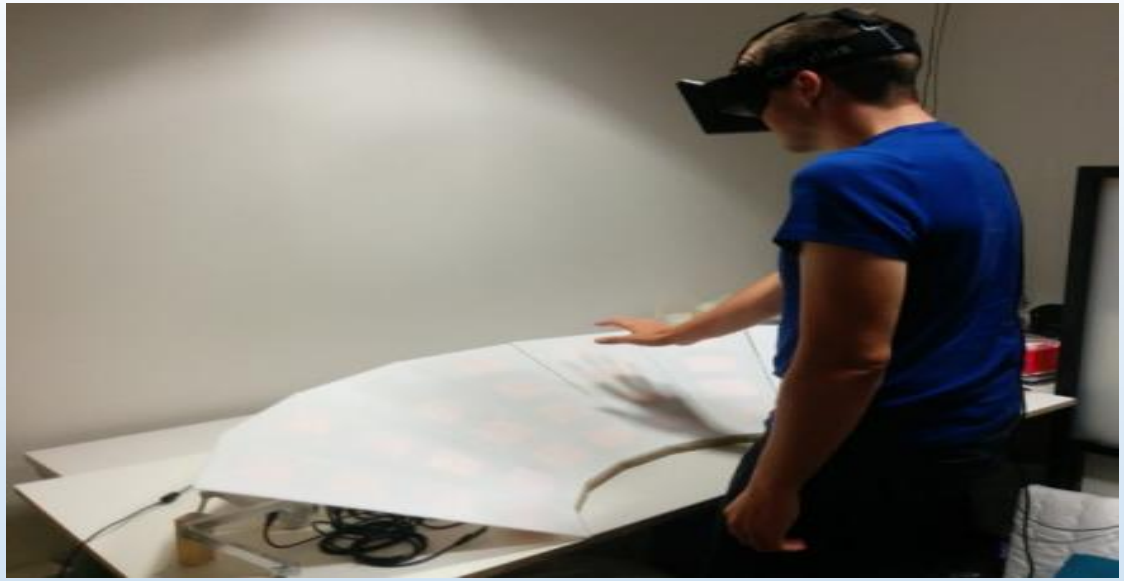




[17] Braun, A., Krepp, S. and Kuijper, A., 2015, June. Acoustic tracking of hand activities on surfaces. In *Proceedings of the 2nd international Workshop on Sensor-based Activity Recognition and Interaction* (p. 9). ACM.



[18] Braun, A., Zander-Walz, S., Majewski, M. and Kuijper, A., 2017. Curved-free-form interaction using capacitive proximity sensors. *Procedia Computer Science*, *109*, pp.59-66.



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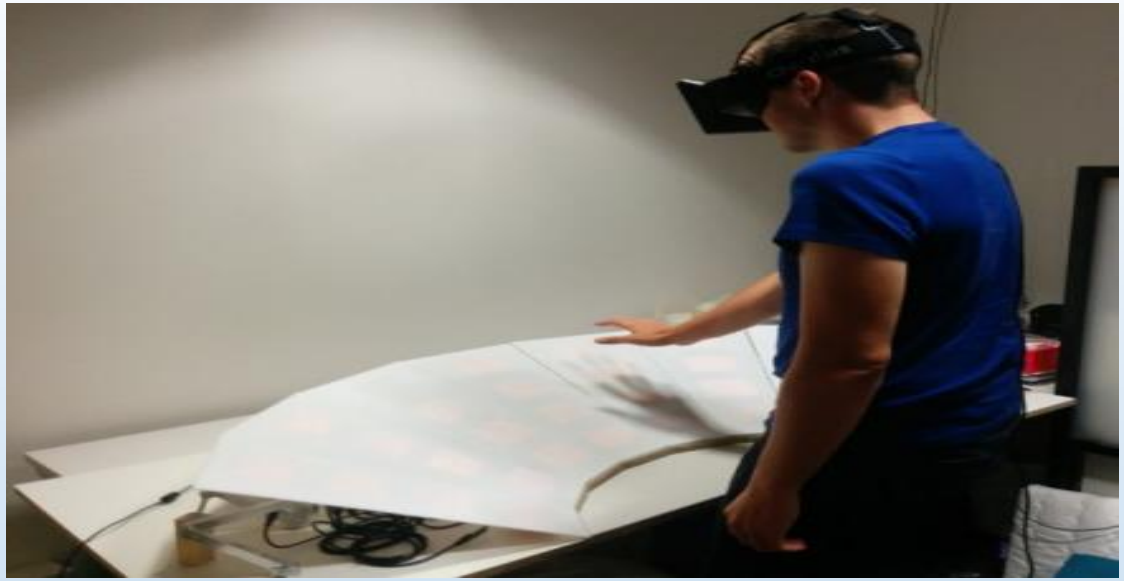

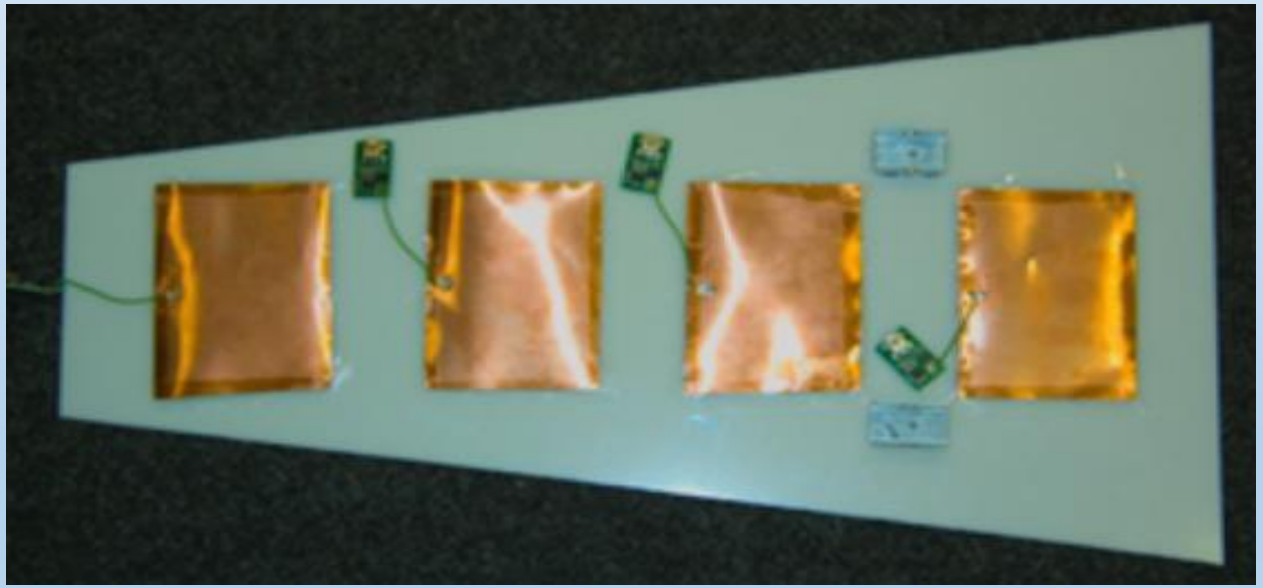

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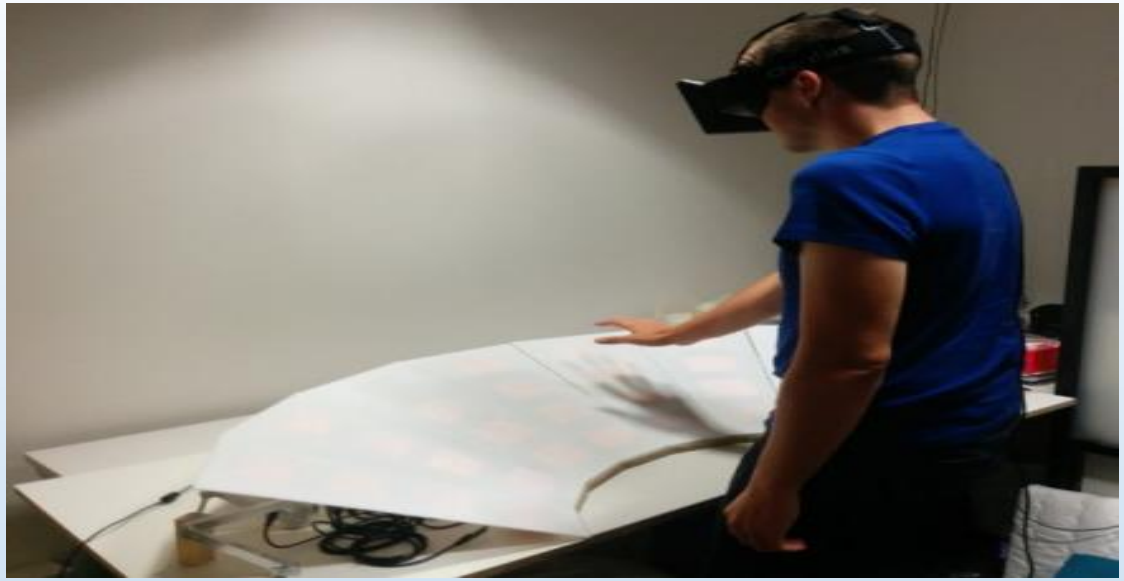
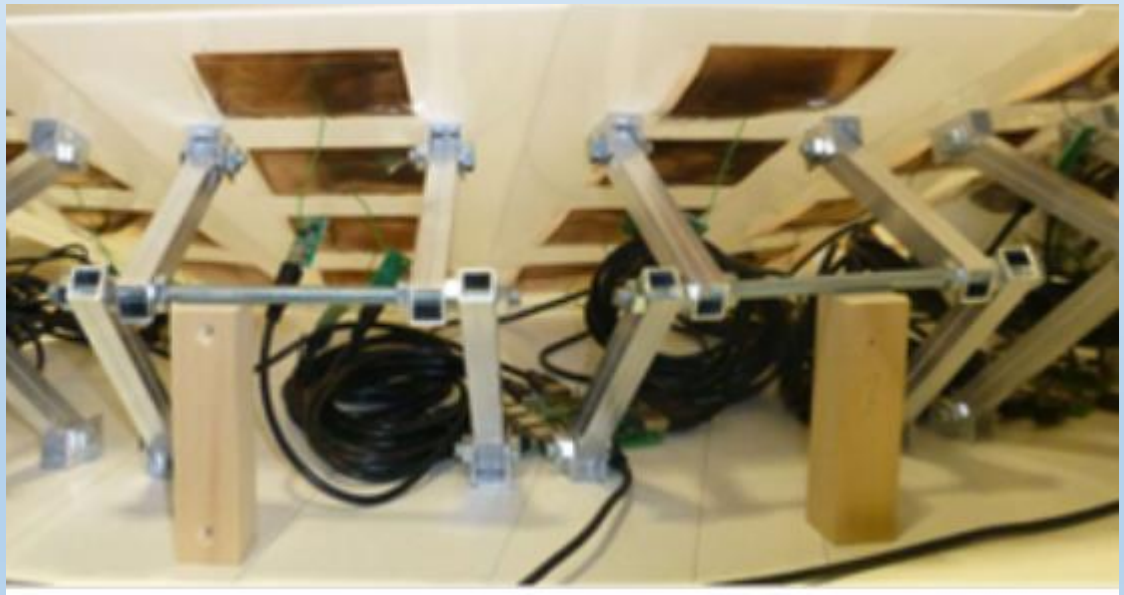
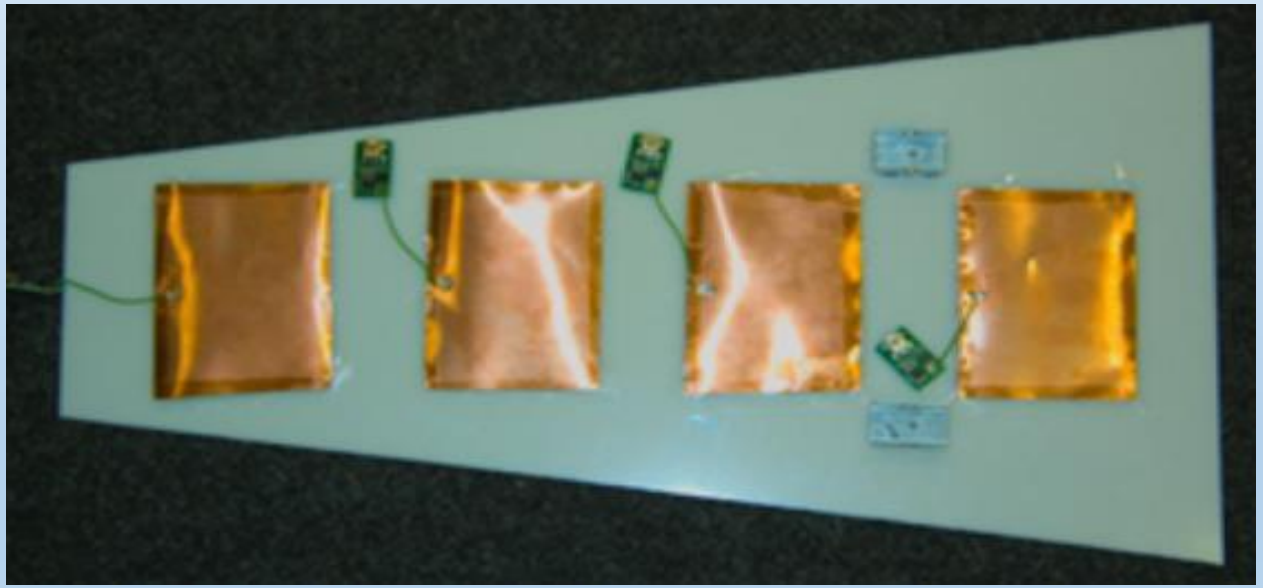
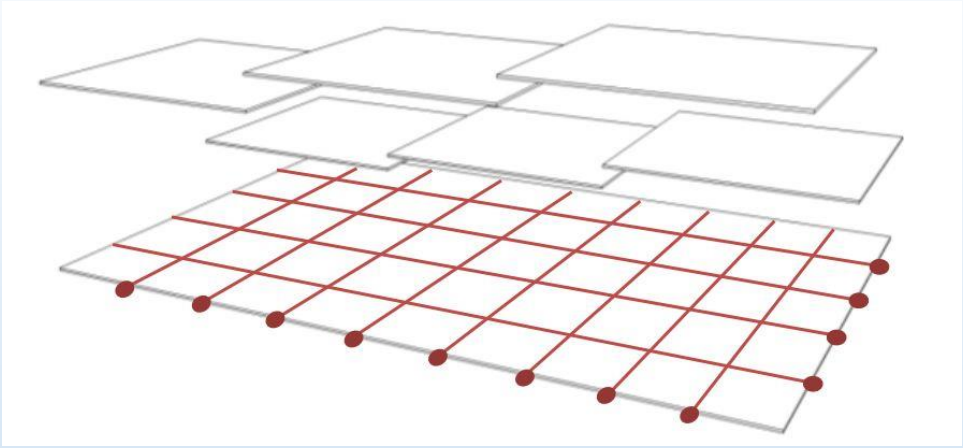






[18] Braun, A., Zander-Walz, S., Majewski, M. and Kuijper, A., 2017. Curved-free-form interaction using capacitive proximity sensors. *Procedia Computer Science*, *109*, pp.59-66.

Smart Floor



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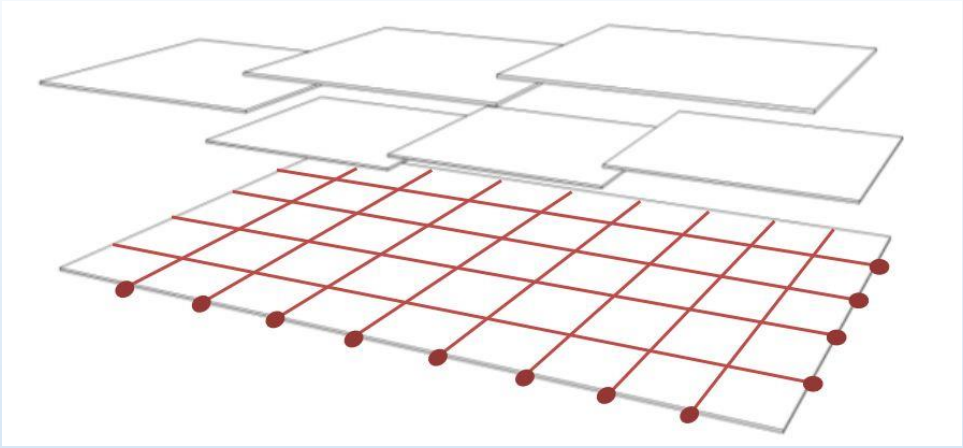

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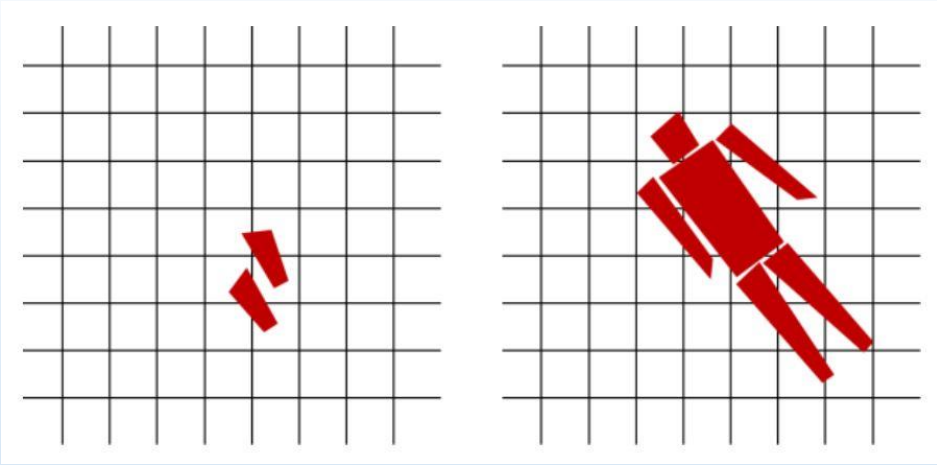
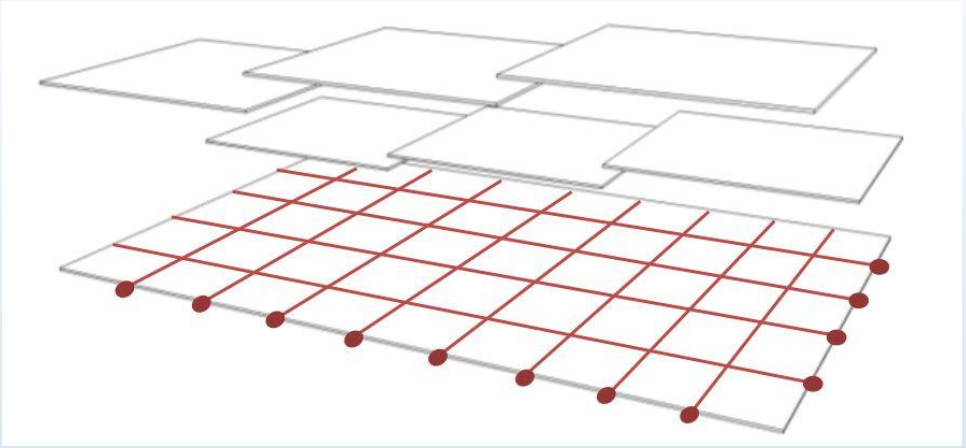


[19]

[19]A. Braun,R. Wichert, A.Kuijper and D.W. Fellner, Capacitive proximity sensing in smart environments. *Journal of Ambient Intelligence and Smart Environments*, 2015 , pp.483-510.



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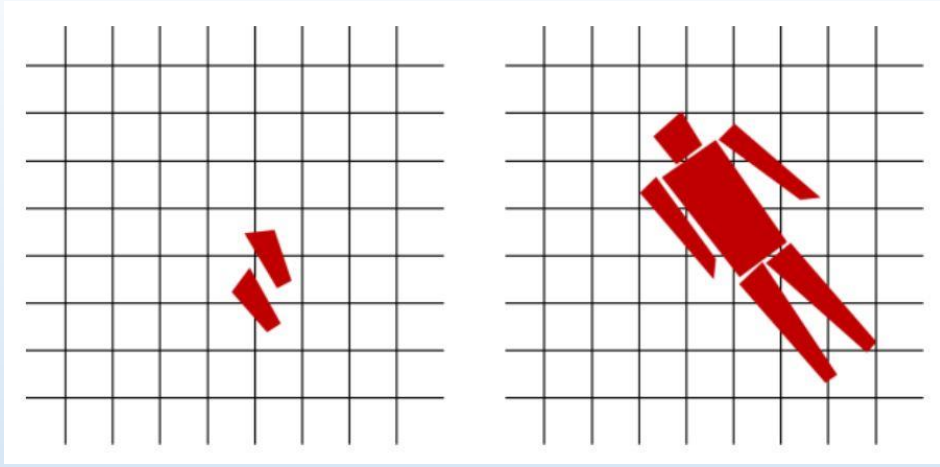

[19]

[20]

[19]A. Braun,R. Wichert, A.Kuijper and D.W. Fellner, Capacitive proximity sensing in smart environments. *Journal of Ambient Intelligence and Smart Environments*, 2015 , pp.483-510.

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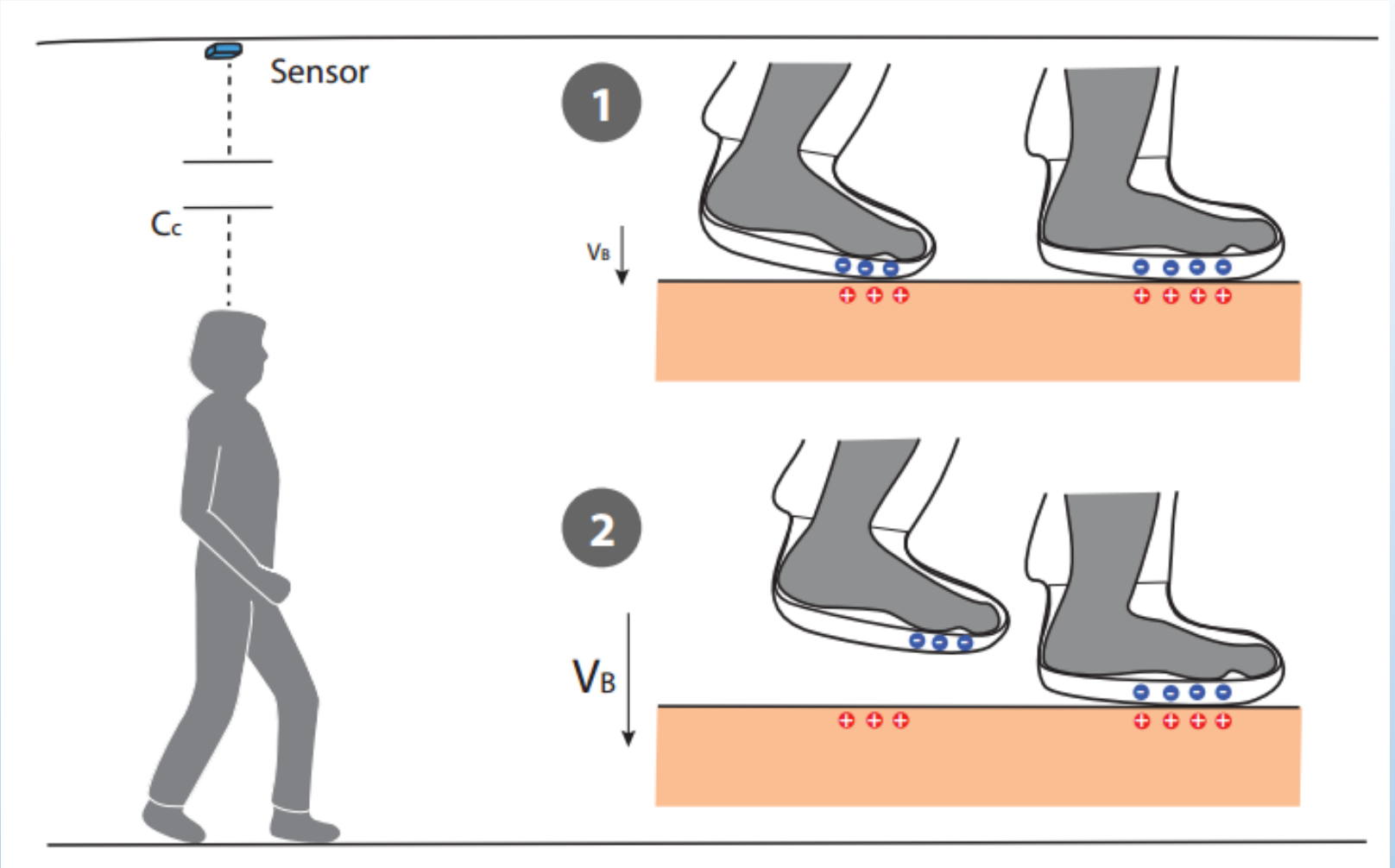
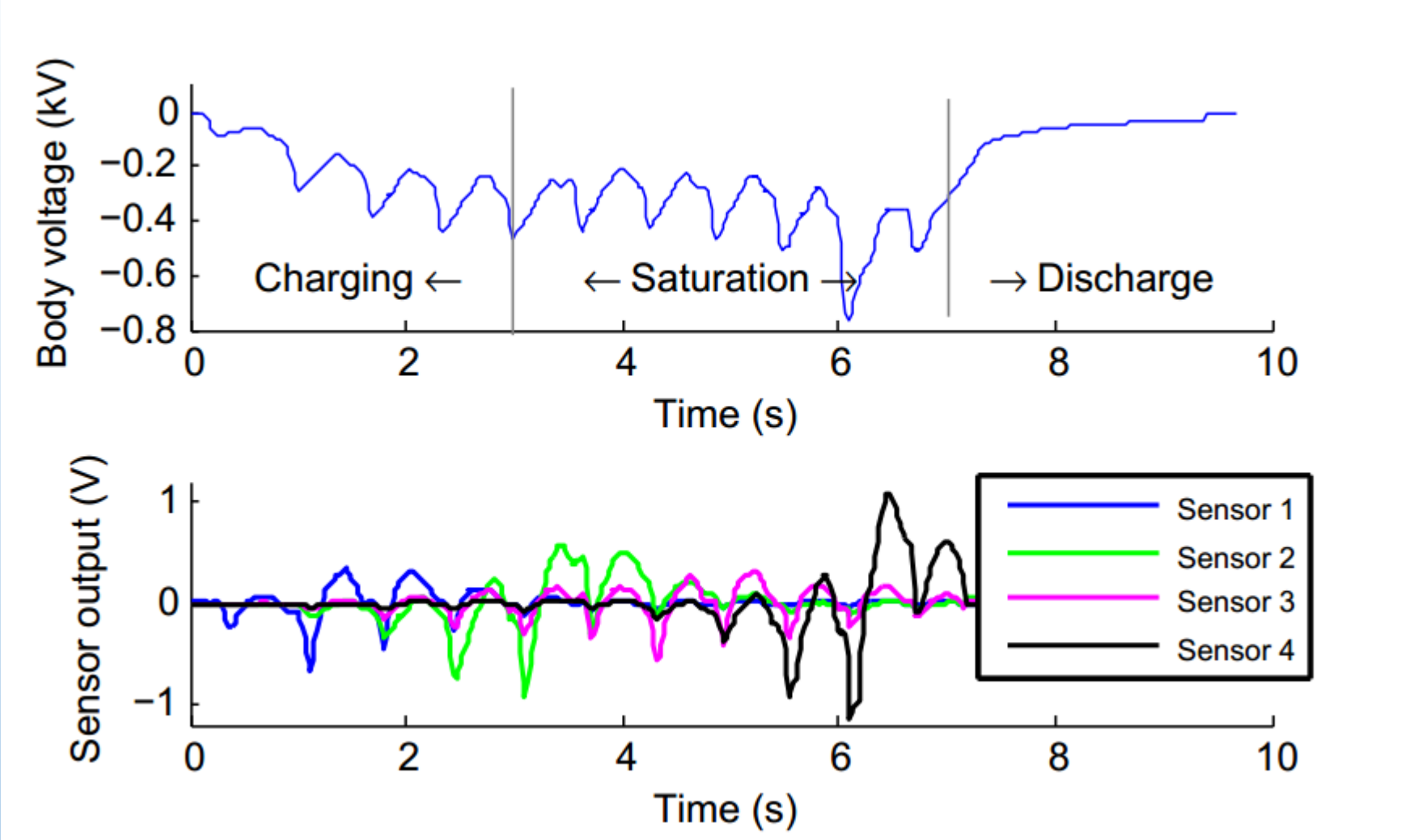


[21] Grosse-Puppendahl, T., Dellangnol, X., Hatzfeld, C., Fu, B., Kupnik, M., Kuijper, A., Hastall, M.R., Scott, J. and Gruteser, M., 2016, June. Platypus: Indoor Localization and Identification Through Sensing of Electric Potential Changes in Human Bodies. In *Proceedings of the 14th Annual International Conference on Mobile Systems, Applications, and Services* (pp. 17-30). ACM.



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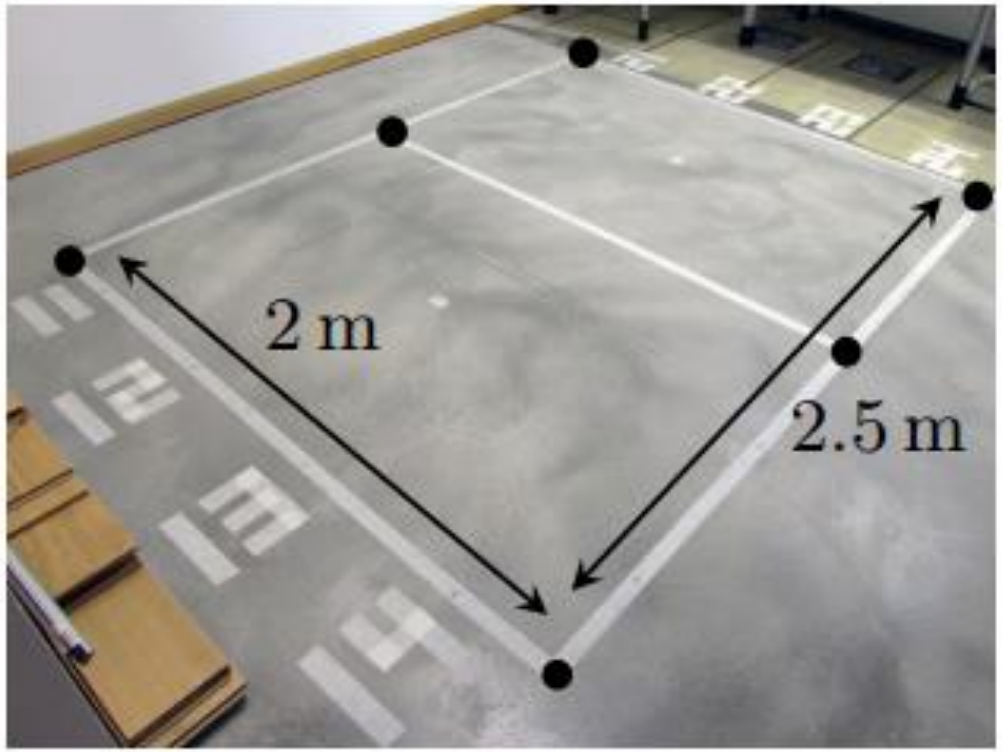

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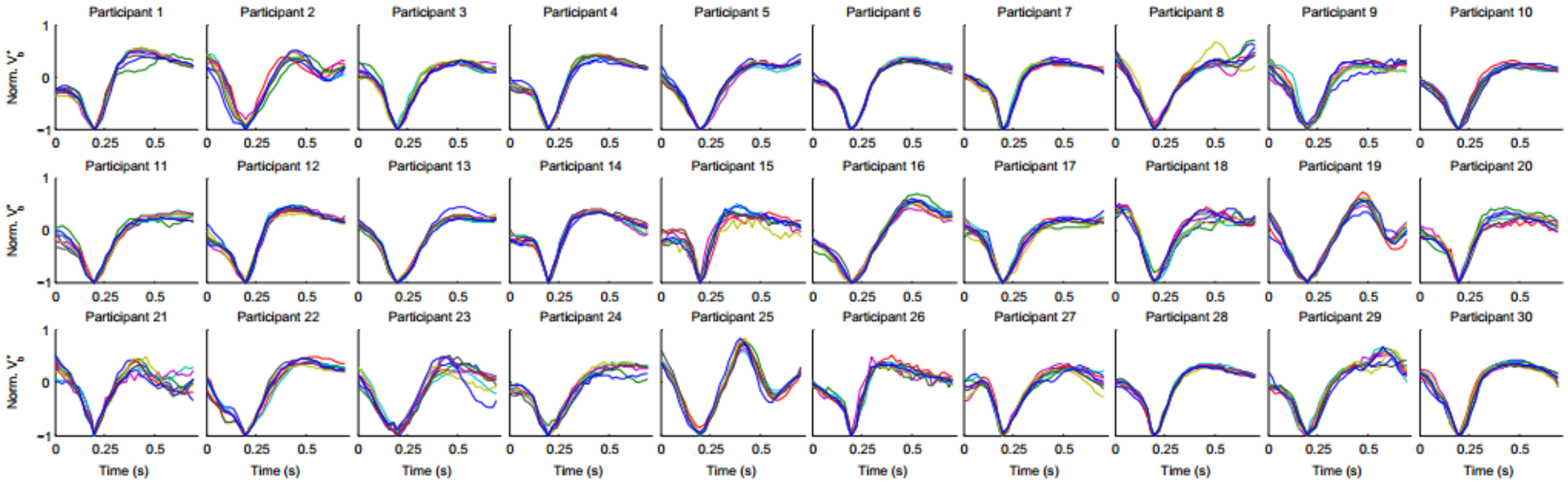
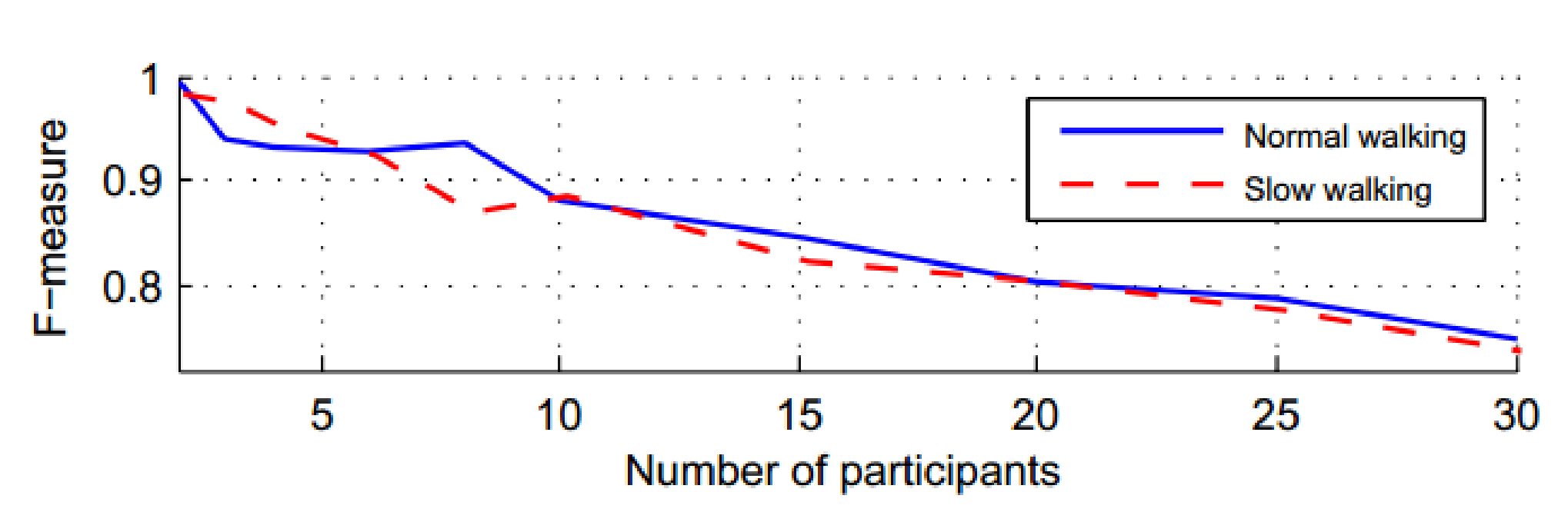


Figure 13: The estimated body electric potential changes when taking a step (step signatures) differ from user to user and represent a discriminative measure for classification. The amplitudes depend on the actually carried charge and require normalization.

[21] Grosse-Puppendahl, T., Dellangnol, X., Hatzfeld, C., Fu, B., Kupnik, M., Kuijper, A., Hastall, M.R., Scott, J. and Gruteser, M., 2016, June. Platypus: Indoor Localization and Identification Through Sensing of Electric Potential Changes in Human Bodies. In *Proceedings of the 14th Annual International Conference on Mobile Systems, Applications, and Services* (pp. 17-30). ACM.

[21] Grosse-Puppendahl, T., Dellangnol, X., Hatzfeld, C., Fu, B., Kupnik, M., Kuijper, A., Hastall, M.R., Scott, J. and Gruteser, M., 2016, June. Platypus: Indoor Localization and Identification Through Sensing of Electric Potential Changes in Human Bodies. In *Proceedings of the 14th Annual International Conference on Mobile Systems, Applications, and Services* (pp. 17-30). ACM.



[21] Grosse-Puppendahl, T., Dellangnol, X., Hatzfeld, C., Fu, B., Kupnik, M., Kuijper, A., Hastall, M.R., Scott, J. and Gruteser, M., 2016, June. Platypus: Indoor Localization and Identification Through Sensing of Electric Potential Changes in Human Bodies. In *Proceedings of the 14th Annual International Conference on Mobile Systems, Applications, and Services* (pp. 17-30). ACM.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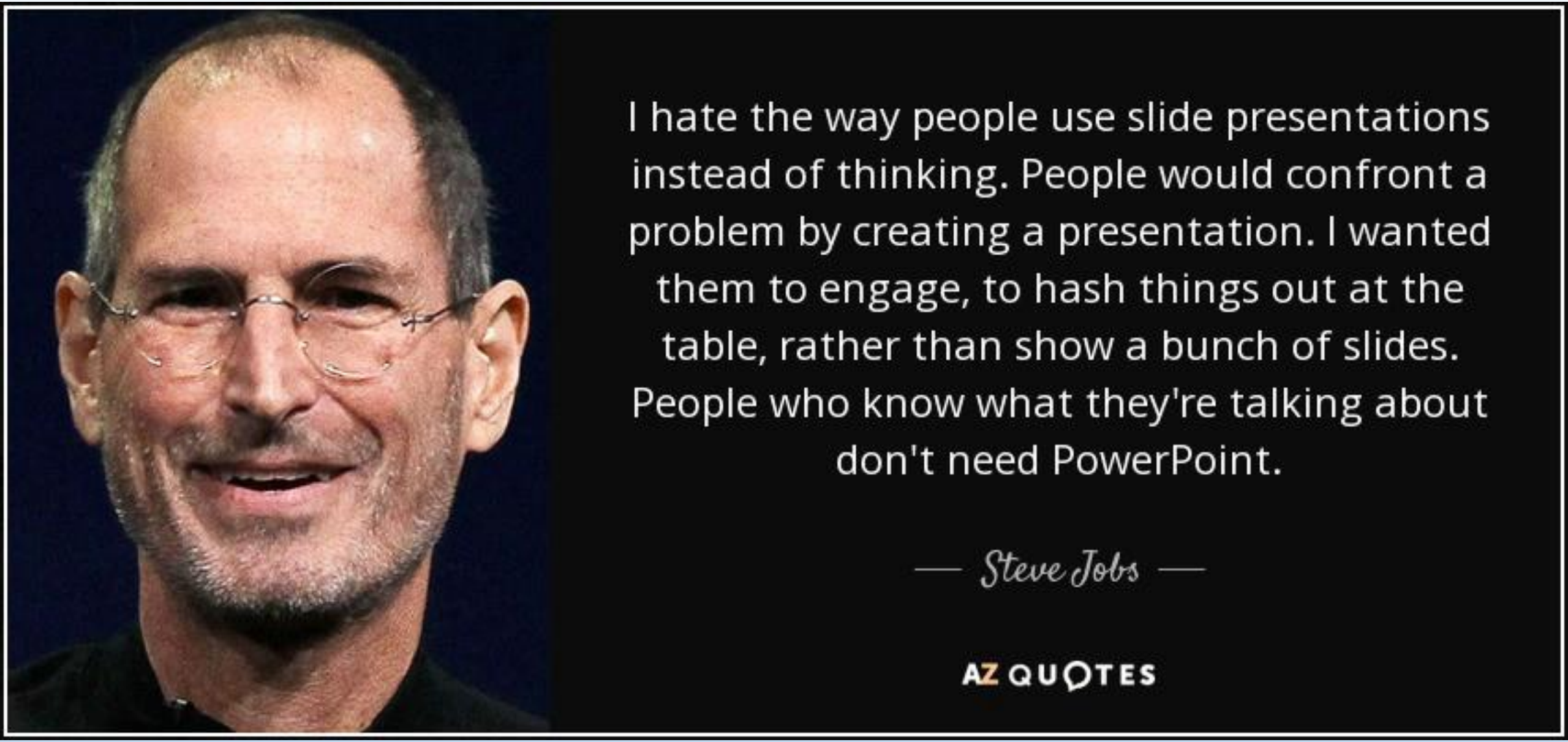
thank you all!


I hate the way people use slide presentations instead of thinking. People would confront a problem by creating a presentation. I wanted them to engage, to hash things out at the table, rather than show a bunch of slides. People who know what they're talking about don't need PowerPoint.
— Steve Jobs —
AZ QUOTES