2nd URSI AT-RASC, Gran Canaria, 28 May – 1 June 2018

A Scalable Textile Antenna Mat for Wireless Sensing of Children's Height

Keren Zhu(1), Lisa Militello(2), and Asimina Kiourti(1), *Member, IEEE*
(1) The ElectroScience Laboratory, Department of Electrical and Computer Engineering, The Ohio State University
Columbus, OH, 43212, USA, https://electroscience.osu.edu/
(2) College of Nursing, The Ohio State University, Columbus, OH, 43210, USA

Abstract

A novel scalable textile antenna mat is proposed for wireless sensing of children's height on the go. Compared to state-of-the-art height measurement techniques (stadiometers, infantometers, etc.), the proposed approach implies: (1) unobtrusive and comfortable operation without much impact to the child's natural activity, and (2) automated, fast, and regular data collection. The operating principle lies on multiple parallel dipole antennas placed at a fixed distance from each other. The two antennas nearest to the edge are transmitting one at a time, while the rest are receiving. The subject's length can be identified as the distance between the two receiving antennas closest to the transmitting ones that have a significant decrease in their transmission coefficient when the child lies upon the mat. Performance of the proposed mat is herewith validated via Finite Element (FE) simulations. In the future, this technology could be integrated into baby cribs or bed sheets to help detect conditions such as Turner syndrome, growth hormone deficiency (GHD) and Celiac (coeliac) disease.

1. Introduction

Regular monitoring of children's height has emerged as a critical factor for early detection/prevention of several conditions, such as Turner syndrome, growth hormone deficiency (GHD) and Celiac (coeliac) disease [1]-[3]. However, statistics show that children's height is currently monitored far less frequently than the American Academy of Pediatrics recommends [4]. In fact, several challenges still remain to be addressed in this area, including: (1) lack of regular well-child medical visits [5], (2) cumbersome, time-consuming, and uncomfortable height measuring equipment (infantometers, stadiometers, etc.) [6], and (3) inconvenient, time-consuming, and manual input of height data into the analyzing computer.

In this paper, we present a novel unobtrusive, wireless, and comfortable textile antenna mat that automatically senses children's height to help predict/prevent related health conditions [1]-[3]. In brief, the proposed mat consists of multiple parallel dipole antennas placed at a fixed distance from each other. The two edge antennas are transmitting, one at a time, while the rest are receiving. Two sweeps are conducted to identify the two receiving antennas closest to the transmitting ones whose transmission coefficients significantly decrease due to the overlying human subject. In doing so, children's height can be readily calculated on the go.

The proposed technology can be easily integrated into several day-to-day products, including baby cribs, bed sheets, and rollable wall art. In addition, it has no impact on the individual's natural activities, requires zero rigid components, is comfortable and soft to touch, and provides automatic wireless height data collection. Collected data can eventually be wirelessly transferred/inputted to a nearby computer or any personal digital assistant (PDA) device (cell phones, tablets, etc.).

2. Operation Principle

Operation of the proposed height-sensing mat is summarized in Figure 1. As seen, the mat contains multiple dipole antennas placed at a fixed distance *d* from each other. To increase the detection surface area, asymmetric dipoles are selected. The two edge antennas are transmitting, one at a time, while the rest are receiving. When a subject lies on top of the mat, he/she blocks the underlying antennas, and decreases, in turn, their transmission coefficient values. As such, the child's height can be calculated by identifying the two antennas closest to the transmitting ones that exhibit degraded transmission coefficients ("starting underlying antenna" and "ending underlying antenna" in Figure 1, respectively). To do so, a front- and back-sweep are proposed in which the leftmost and the rightmost antennas are, respectively, transmitting. As a first step, the free-space transmission coefficients are collected for the front- and back-sweep cases (i.e., when no phantom is present). Subsequently, the starting and ending underlying antennas are identified as the first antennas that show degraded transmission coefficient values vs. those measured for the free-space scenario. That is, the front sweep serves to identify the "starting underlying antenna" while the back sweep identifies the "ending underlying antenna". The distance between these antennas is defined as *Ld* in Figure 1. Finally, height of the subject can be calculated as:

$$Height(Lphtm) = Ld + d \quad (1).$$

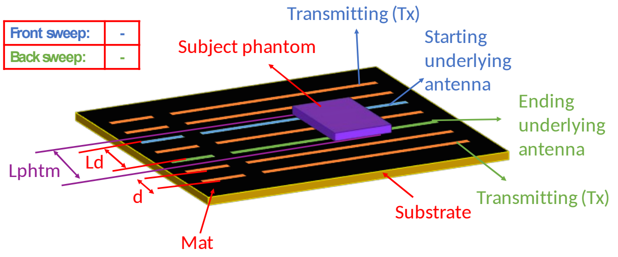


Figure 1. Operation principle of the proposed textile mat for unobtrusively sensing children's height.

3. Simulation Set-up and Results

To demonstrate the height measuring capabilities of the proposed mat, Finite Element (FE) simulations were conducted. Figure 2 summarizes the design parameters of our proof-of-concept mat and the employed tissue-emulating phantoms. Specifically, two phantoms (ε_r = 56.8, σ = 1.07 S/m) were employed to emulate the human torso (rectangular) and human torso/head (rectangular attached to a sphere) [7]. Thickness of the rectangular cuboids was selected to be only 1 cm, as a worst-case scenario. Expectedly, thicker phantoms would provide more significant differences in the desired transmission coefficient values. The overall length of both phantoms (to be retrieved) was equal to 16cm. The Industrial Scientific and Medical (ISM) band of 915MHz was selected for wireless transmission, and felt (ε_r = 1.45, σ ≈ 0 S/m) was set as the mat's base material. For this particular example, the mat consisted of 16 dipoles, all of which were modeled as perfect electric conductors (PEC). The overall mat size was equal to 52 cm × 43 cm. Radiation boundaries were set more than λ/4 away from the structure.

Based on the above, two scenarios were explored for each for the two phantoms, namely Scenario A and Scenario B in Table 1. Our utmost goal was to confirm that the mat could accurately derive the phantoms' height regardless of their shape. To do so, the first step was to ensure that all antennas printed on the mat resonate at 915 MHz (i.e., reflection coefficient at 915 MHz is < -10 dB). Indeed, the simulated reflection coefficient values for all 16 antennas are given in Figure 3, and are shown to meet the pre-set target. As a second step, we calculated the difference in transmission coefficients when no phantom was lying upon the mat vs. the case where the phantom was placed upon the mat. These differences are shown in Figure 4 for Scenarios A and B. The "starting underlying antenna" and "ending underlying antenna" can be clearly identified as the first receiving antennas on each end, respectively, that exhibit a significant decrease in transmission coefficient (i.e., transmission coefficient difference is < -5 dB). The phantoms' heights were calculated using Eq. 1 as listed in Table 2. For both scenarios, the simulation results indicating the correct phantom length of 16 cm.

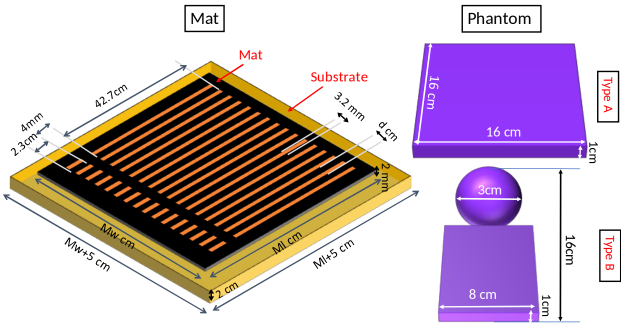


Figure 2. Proof-of-concept simulation set-up: mat design and employed tissue-emulating phantoms.

Table 1. Employed simulation scenarios.

	Scenario A	Scenario B
Mat (felt) size (Mw × Ml)	52 cm × 43 cm	52 cm × 43 cm
# of dipole antennas	16	16
Distance between dipoles (d)	2 cm	2 cm
Dipole thickness	3.2 mm	3.2 mm
Substrate thickness	2 cm	2 cm
Phantom	Type A	Type B

Table 2. Actual vs. calculated phantom heights.

	Scenario A	Scenario B
Actual phantom height	16 cm	16 cm
Staring-Ending underlying antennas	#5-#12	#5-#12
Distance between antennas (d)	2 cm	2 cm
Calculated length (Lphtm)	14 + 2 = 16 cm	14 + 2 = 16 cm

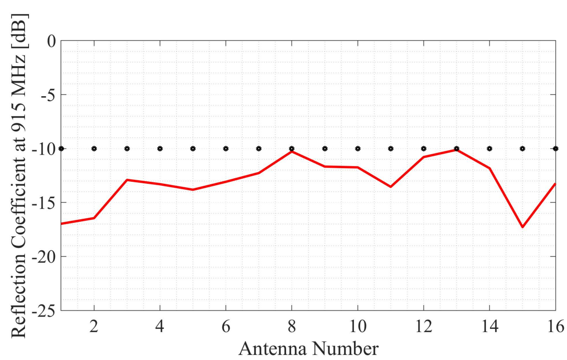
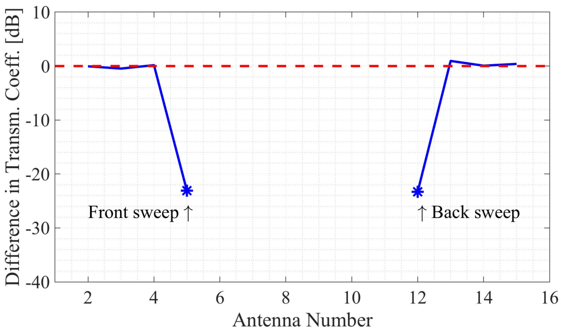
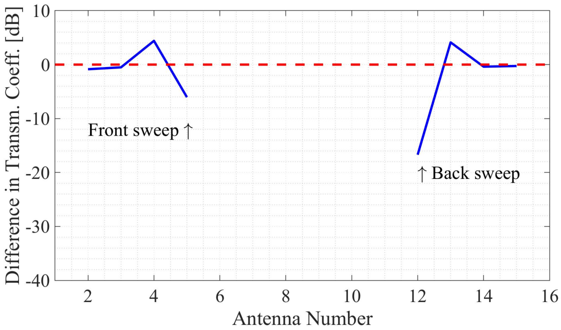


Figure 3. Reflection coefficient at 915 MHz for all 16 antennas printed on the poof-of-concept mat of Figure 2.



(a)



(b)

Figure 4. Difference in transmission coefficients when no phantom is lying upon the mat vs. the case where the phantom is placed upon the mat: (a) Scenario A, and (b) Scenario B.

4. Conclusion

In this work, a novel scalable textile antenna mat was presented for wireless height monitoring. Simulation results for the proposed proof-of-concept antenna mat have shown to accurately derive the height of the overlying phantom. Notably, height can be accurately retrieved regardless of the exact phantom shape. Contrary to existing height measurement techniques (infantometers, stadiometers, etc.), the proposed method can monitor a child's height unobtrusively, wirelessly and comfortably, potentially at low burden and cost. As such, this technique can be used for numerous applications: smart baby crib regularly collecting height data, height monitoring children's bed sheets, rollable height detection mats, etc. Measurement results will be presented at the conference. In the future, the proposed design could be embroidered upon the mat using conductive E-threads [8].

5. Acknowledgements

The authors would like to thank Harsh Singhania (undergraduate student at Ohio State's ECE Dept.) for his assistance with the preliminary steps of this work.

6. References

1. L. Sävendahl and M. L. Davenport, "Delayed diagnoses of Turner's syndrome: Proposed guidelines for change," *The Journal of Pediatrics*, **137**, 4, October 2000, pp. 455-459, doi:10.1067/mpd.2000.107390.

2. M. Gasparetto, "Crohns disease and growth deficiency in children and adolescents," *World Journal of Gastroenterology*, **20**, 37, October 2014, p. 13219-13233, doi:10.3748/wjg.v20.i37.13219.

3. C. R. Kahrs, M. C. Magnus, H. Stigum, K. E. A. Lundin, and K. Størdal, "Early growth in children with coeliac disease: a cohort study," *Archives of Disease in Childhood*, **102**, 11, June 2017, pp. 1037–1043, doi: 10.1136/archdischild-2016-312304.

4. J. F. Hagan, J. S. Shaw, and P. M. Duncan, "Bright futures: guidelines for health supervision of infants, children, and adolescents," *Elk Grove Village, IL: Bright Futures/American Academy of Pediatrics,* 2017.

5. U.S. Department of Health and Human Services, Health Resources and Services Administration, Maternal and Child Health Bureau. "Child Health USA 2014," *Rockville, Maryland: U.S. Department of Health and Human Services*, 2015.

6. M. D. Onis, A. W. Onyango, J. V. D. Broeck, C. W. Chumlea, and R. Martorell, "Measurement and Standardization Protocols for Anthropometry Used in the Construction of a New International Growth Reference," *Food and Nutrition Bulletin*, **25**, 1, March 2004, pp. S27-S36, doi:10.1177/15648265040251S104.

7. K. Chan, R. Cleveland, D. Means, "Evaluating compliance with FCC guidelines for human exposure to radiofrequency electromagnetic fields", *OET Bulletin 65*, **Supplement C**, 1997, pp. 97-01.

8. A. Kiourti, C. Lee, and J. L. Volakis, "Fabrication of Textile Antennas and Circuits With 0.1 mm Precision," *IEEE Antennas and Wireless Propagation Letters*, **15**, May 2015, pp. 151-153, doi:10.1109/LAWP.2015.2435257.