UNIVERSITY OF BIRMINGHAM

MIMO Sensor Array for Short-Range High-Resolution Automotive Sensing

misl

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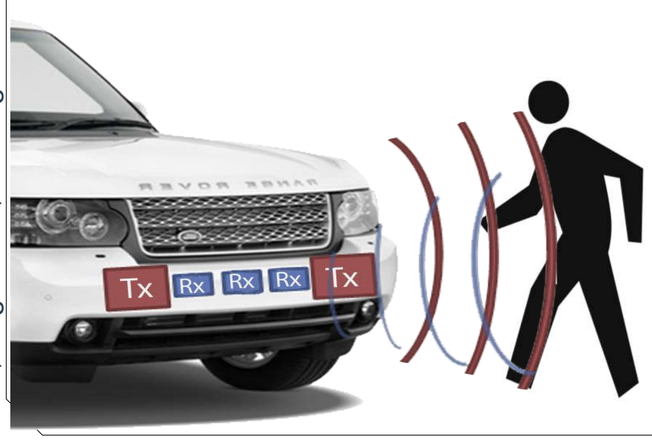
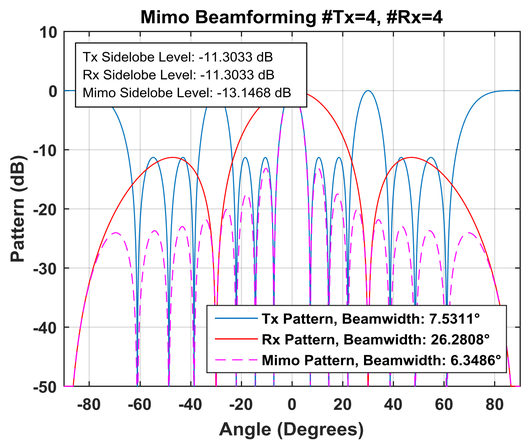
1.Introduction

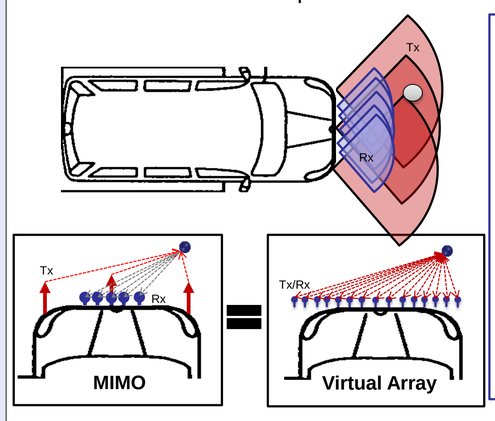
The aim of the project is to investigate a novel Multiple-Input-Multiple-Output (MIMO) sensor system for automotive applications. Compared to traditional phased arrays, a MIMO array can achieve the same fine angular resolution, but with a drastically reduced amount of sensor elements. A MIMO array of 8 elements can deliver the same resolution as a phased array of 16 elements [1]. The other highlight of this technology is that it can operate at short ranges, which is physically impossible with a phased array as the beam requires significant distance from the antenna aperture to form [2]. Therefore a MIMO system can potentially provide very high angular resolution at short ranges. These properties make such a system attractive for a number of automotive applications, including parking aids, short-range cruise control, speed-over-ground estimation, pedestrian and object detection and collision detection.

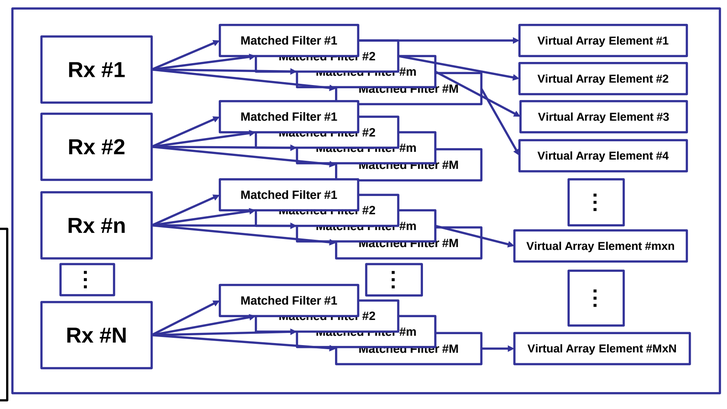




2.Phased vs. MIMO Array

A phased-array-antenna radar can be used with beam-forming techniques to direct a beam to a specific location [3]. And then the radar can scan the desired area electronically. This can be achieved since, the correlated signals from transmit antennas would add up constructively or destructively in different directions in space [2]. On the other hand, a MIMO radar uses the advantage of orthogonality for various advantages [4]. These advantages can be; reduced amount of necessary array elements, increased angular resolution, faster scan time, simultaneous search & track etc. With a MIMO array; beamforming process does not have to happen in the space but in the digital space, so we can "illuminate" the whole space of interest with single transmission [1].

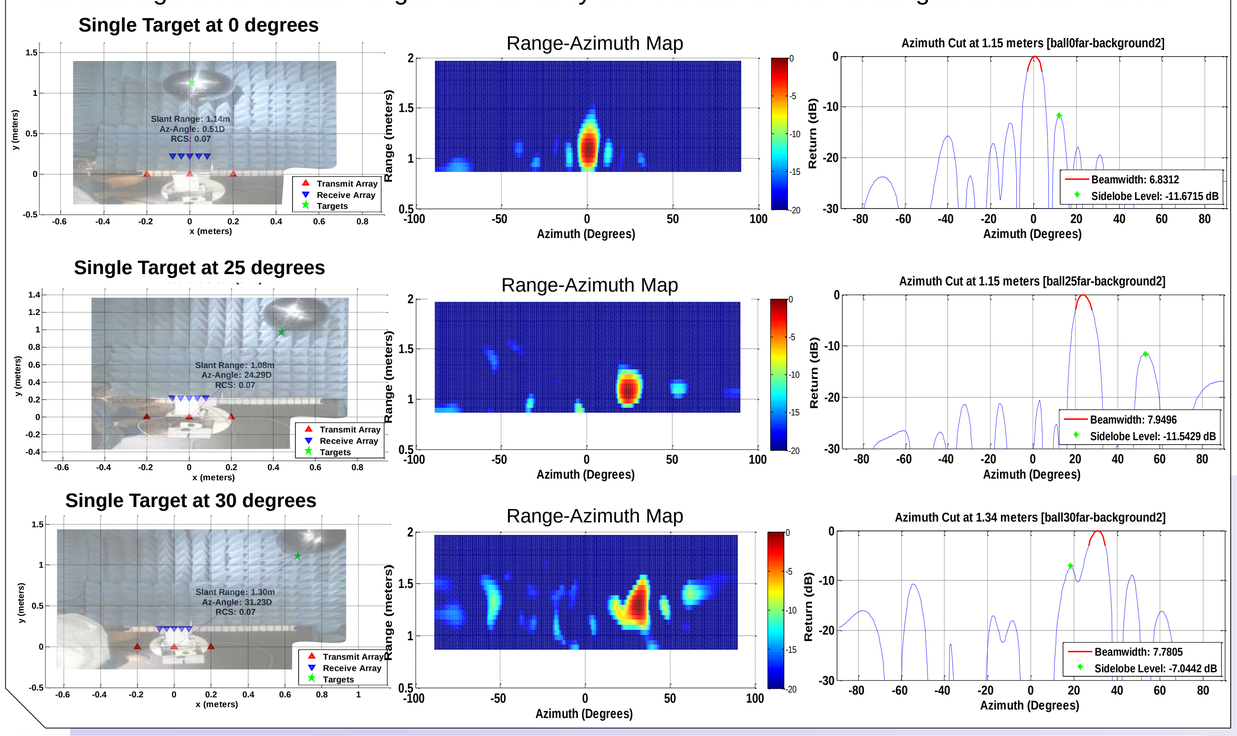




- Matched filtered signals can be interpreted as the signals out of the virtual array elements.
- Virtual Array Concept: M+N MIMO elements give the same angular resolution of MxN phased array
- Drastic reduction in antenna elements
- Example: 4+4 MIMO = 4x4 Phased Array
- Cheaper and more diverse system

3. Nearfield MIMO

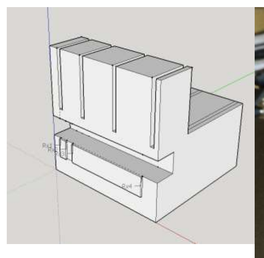
Nearfield MIMO techniques can be used for scanning areas without losing focus in close ranges with a tradeoff with more computation. The solution uses an actual geometric model rather than a far-field approximated model to derive the array factor[5][6]. Below are our experimental results from our nearfield algorithms at close ranges with an array with the size of 40cm looking at about 1.1 metres.

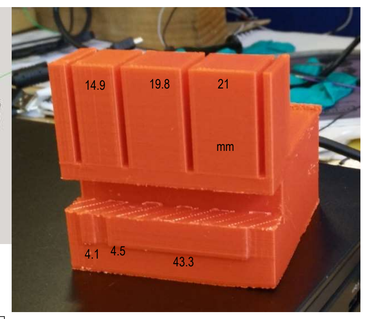


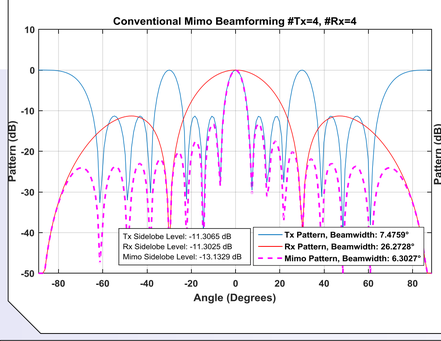
4. Nonlinear MIMO

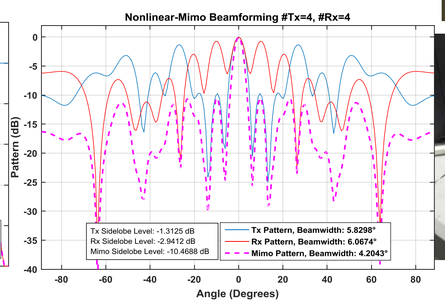
To further optimize the MIMO arrays, we looked into thinned arrays. Since MIMO array patterns are obtained from their equivalent virtual arrays, optimizing MIMO array patterns is not a straightforward job. To achieve this task, we utilized various optimization algorithms to find solutions; namely random descent[7][8], simulated annealing[9][10] and genetic algorithm[11][12]. Our specialized implementations of these algorithms have successfully yielded us practical solutions. Below is a comparison of a conventional MIMO array and one of our Nonlinear MIMO arrays.

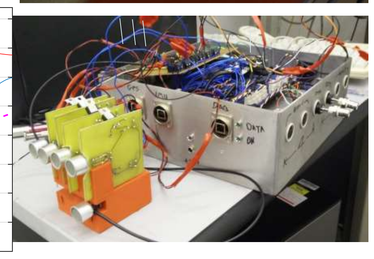
(Scanning 0 degrees)	# of Elements	Beamwidth	Sidelobe Level	Equivalent PA Elements
Conventional MIMO (sim)	8 (4+4)	6.30	-13.1 dB	16
Conventional MIMO (exp)	8 (4+4)	6.48	-12.9 dB	16
Nonlinear MIMO (sim)	8 (4+4)	4.20 (~65%)	-10.5 dB	24
Nonlinear MIMO (exp)	8 (4+4)	4.25 (~65%)	-7.3 dB	24





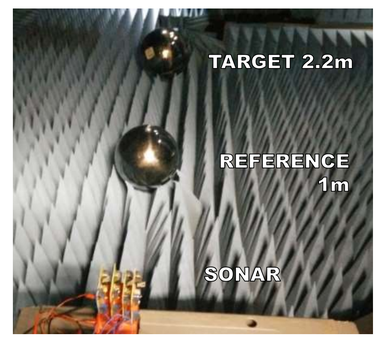


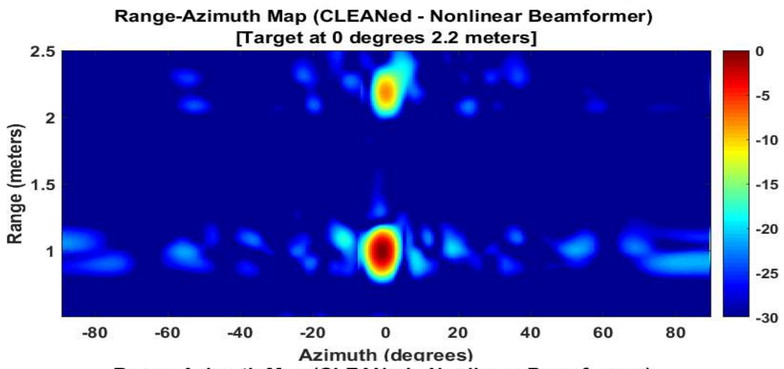


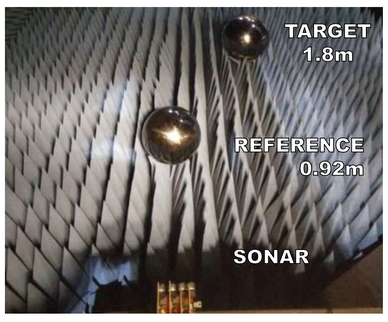


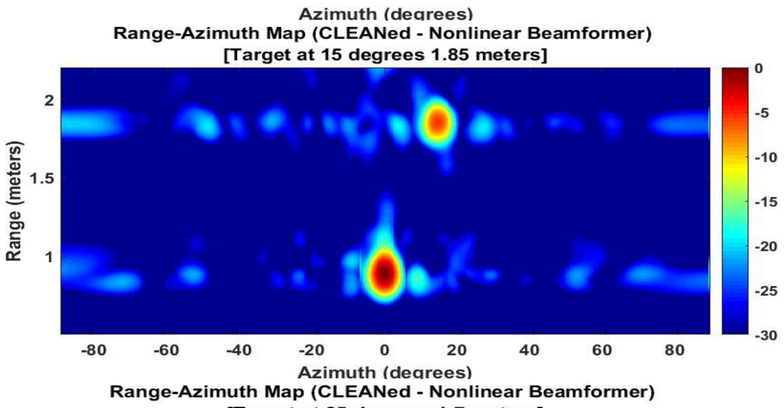
5.Experimental Results

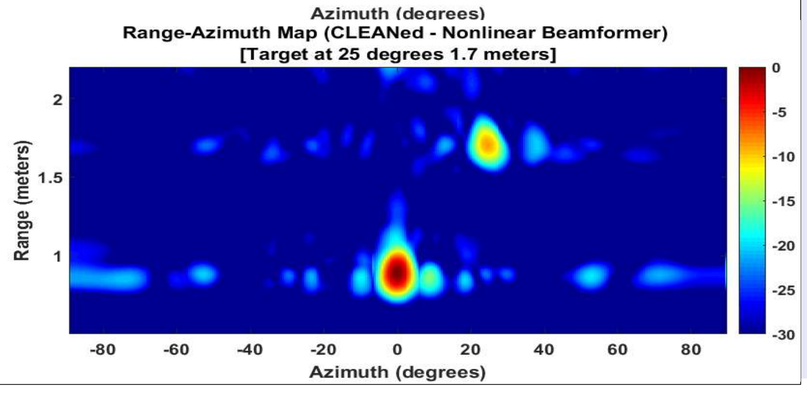
Less reflective targets can be disguised as range/angular sidelobes. Or the reverse can happen; angular/range sidelobes can constructively add up to create fake targets. To overcome these problems CLEAN algorithm was modified for our purposes, which is mainly used in radio astronomy[13].











6. Conclusions

- MIMO concept applied to automotive context
- Obtained further performance improvements
- Produced acoustic technology demonstrator, tested and verified
- Technology is not limited to sonar, can be moved into RF domain (e.g. for higher maximum range)

7. Future Work

- Practical MIMO Applications
  - Taking an image of a practical object with conventional MIMO
  - Taking an image of a practical object with Non-Linear MIMO (e.g. bicycle, baby cart)
- Replacing receivers with miniature SMD components
  - To have a fully functional "plug and play" prototype

8.References

[1] D. Bliss, K. Forsythe, and G. Fawcett, 'MIMO Radar: Resolution, Performance, and Waveforms', in Proc. 14th Annual Adaptive Sensor Array Processing Workshop, MIT, 2006, pp. 6–7.
[2] C. A. Balanis, Antenna theory: analysis and design, 3rd ed. Hoboken, NJ: John Wiley, 2005, ISBN: 047166782X.
[3] P. Z. Peebles, Radar principles. New York: Wiley, 1998, ISBN: 0471252050.
[4] M. Lesturgie, 'Tutorial on MIMO Radar', Glasgow, UK, 21-September-2012.
[5] R. A. Kennedy, T. Abhayapala, D. B. Ward, and R. C. Williamson, 'Nearfield broadband frequency invariant beamforming', in Acoustics, Speech, and Signal Processing, 1996. ICASSP-96. Conference Proceedings., 1996 IEEE International Conference on, 1996, vol. 2, pp. 905–908,
[6] R. A. Kennedy, D. B. Ward, and P. T. D. Abhayapala, 'Nearfield beamforming using nearfield/farfield reciprocity', in Acoustics, Speech, and Signal Processing, 1997. ICASSP-97., 1997 IEEE International Conference on, 1997, vol. 5, pp. 3741–3744, Available at http://ieeexplore.ieee.org/xpls/abs_all.jsp?arnumber=604683.
[7] N. Mladenović and P. Hansen, "Variable neighborhood search," Comput. Oper. Res., vol. 24, no. 11, pp. 1097 – 1100, 1997 [Online]. Available: http://www.sciencedirect.com/science/article/pii/S0305054897000312
[8] P. Hansen, N. Mladenović, and J. A. Moreno Pérez, "Variable neighbourhood search: methods and applications," Ann. Oper. Res., vol. 175, no. 1, pp. 367–407, Mar. 2010 [Online]. Available: http://link.springer.com/10.1007/s10479-009-0657-6. [Accessed: 16-Apr-2015]
[9] S. Kirkpatrick, M. P. Vecchi, and others, "Optimization by simmulated annealing," science, vol. 220, no. 4598, pp. 671–680, 1983 [Online]. Available: http://leonidzhukov.net/hse/2013/stochmod/papers/KirkpatrickGelattVecchi83.pdf. [Accessed: 20-Apr-2015]
[10] V. Černỳ, "Thermodynamical approach to the traveling salesman problem: An efficient simulation algorithm," J. Optim. Theory Appl., vol. 45, no. 1, pp. 41–51, 1985 [Online]. Available: http://link.springer.com/article/10.1007/BF00940812. [Accessed: 20-Apr-2015]
[11] A. M. Turing, "A quarterly review of psychology and philosophy," Pattern Recognit. Introd. -Dowden Hutchinson Ross Inc, 1973.
[12] J. H. Holland, Adaptation in natural and artificial systems: an introductory analysis with applications to biology, control, and artificial intelligence, 1st MIT Press ed. Cambridge, Mass: MIT Press, 1992.
[13]J. A. Högbom, "Aperture Synthesis with a Non-Regular Distribution of Interferometer Baselines," \aaps, vol. 15, p. 417, Jun. 1974.

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