SnT2017 Poster No. (T3.1-P21)

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Developments in IMS Infrasound Array Geometry Tools

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Abstract: A well planned array geometry is fundamental in the design of state-of-the-art infrasound arrays. The International Monitoring System (IMS) continues to create new and improved tools for use in designing and planning the construction or upgrade of IMS infrasound stations. The following are considered when using the tool: number of array elements, array area, minimum distance between elements, irregular placement, and omnidirectionality. The loss of individual elements is taken into account, while still adhering to all initial requirements. The projection of array geometries onto geographical coordinates allows IMS engineers to not only plan ahead, but to also use these tools in the field and make adjustments on the fly. Though designed for initial array planning, these tools can also be used when considering upgrades such as the relocation of elements at existing infrasound arrays. The new planning technique has been recently implemented in the design of IS01, Argentina and tested on site with promising results. Moving forward, the focus of these design tools remains the optimization of relevant infrasound detections at IMS stations, while bringing greater potential support into station design and/or upgrades.

Current IMS Method for Geometry Planning:

Currently, minimum requirements stated in the IMS Operational Manual for infrasound stations and the previous recommendations made at Infrasound Technology Workshops in 2003 and 2012 are considered when designing possible array geometries for IMS stations. In particular: 1) Analyses of four-element array IMS stations showed them to be to be non-robust with the loss of an element degrading the station's detection capabilities; 2) Eight-element arrays were less vulnerable to such performance degradation; 3) An irregular arrangement of the array elements was deemed to be desirable, as this provides for a better distribution of inter-element spacing than symmetric configurations.

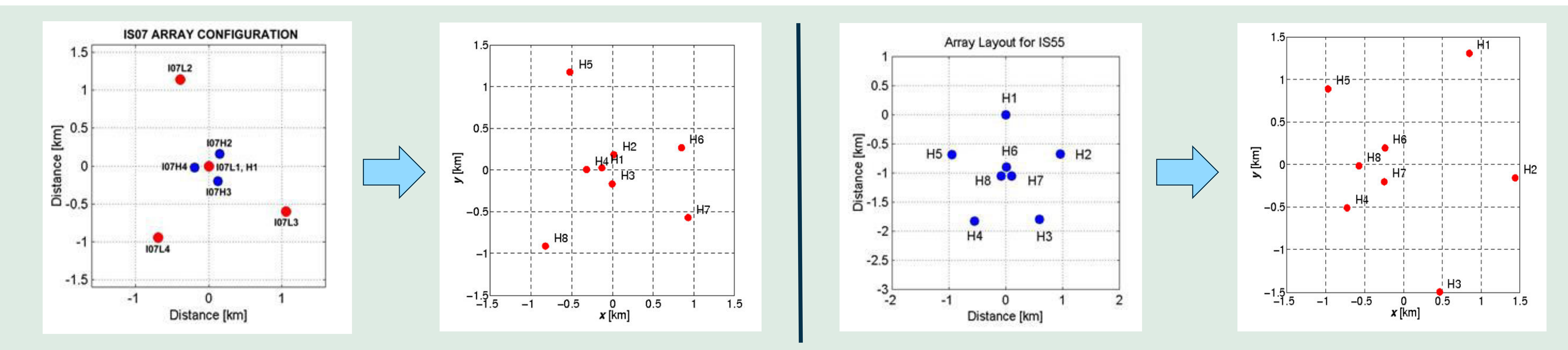


Figure 1: Before and After array geometries for IS07(left), IS55 (right).

The geometries of both IS07 and IS55 (Figure 1) were modified within the last few years to reflect these recommendations. These example stations consist of 8 elements with irregular arrangements, resulting in a more desirable distribution of inter-distances and orientations.

Note: IMS infrasound array geometries are also very dependant on the given land area and the need to place elements in low-noise locations (i.e. away from constant noise sources or in well forested areas (wind-noise protection)).

Creating an Array Geometry Tool:

In order to produce numerous possibilities of irregular array configurations as recommended, software is used to randomly generate locations (elements), over a defined area. Once a set number of elements are generated, several sets of mathematical criteria are checked over multiple scenarios to ensure an optimal geometry. The criteria are based on previous recommendations, IMS requirements, experience drawn upon from the International Data Centre (IDC) and recent state-of-the-art developments.

Considerations for an Array Geometry Tool:

When designing a tool for IMS station array geometry, element failure (power, data link, etc.) is an important consideration (Figure 2). Loss of an element due to noise (i.e. unable to contribute to detections) must also be considered.

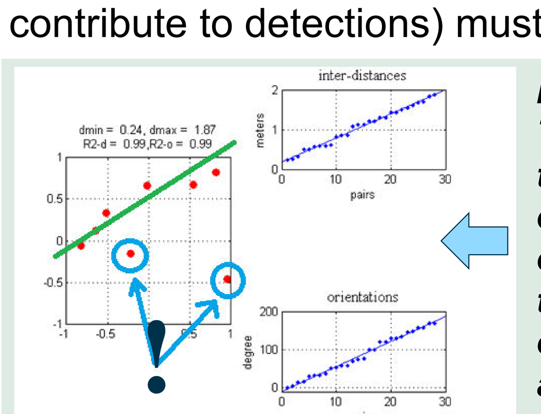


Figure 2: The two lower elements essentially turns the array into one with a linear aperture.

Due to the complexity of accounting for actual terrain, the tool had to be made portable, to allow IMS engineers to recalculate array designs (on-site) in the case of unforeseen obstacles once in the field, e.g. trees, large rocks, manmade obstructions, etc.

Determining Array Geometry Constraints:

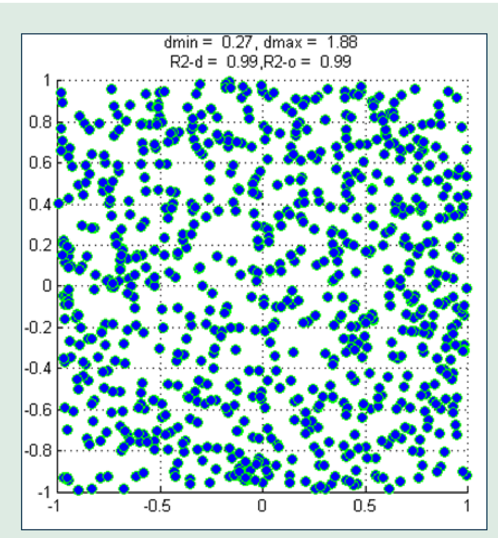
Condition	Constraint/Desired Outcome	Reasoning
Number of elements	8	Eight-element arrays are less vulnerable to performance degradation. Preparatory Commission recommendation.
Array Boundaries	X-Y (meters), array dependent	Bound by geographical or property restrictions.
Element configuration/placement	An irregular arrangement of the array elements is desirable, resulting in a better distributions of inter-element spacing.	Recommendation by Expert Group 2012
Minimum distance between elements	roughly 250 meters	Recommendation from the IDC based experience gained from the IMS network
Omnidirectional array	Geometry should not designed as such, as to favor one azimuth over the other	Recommendation by Expert Group 2012
Mission Capability (MC)	While MC is met, the above 4 conditions should still be met	While MC is met, station should still contribute to Network detections

Defining Constraints within the Tool:

Measurement	What does it tell us?	How is it applied?	What are the realistic limits?
N	The number of elements	Determined by person designing the array	Station is Mission Capable as long as N-M>70%, where M=number of non-functioning elements
X, Y	X and Y represent the dimensions of the rectangular boundaries of the array being designed.	Determined by person designing the array.	Driven by land, but dmin will constrain the lower limit.
R^2 - Coefficient of Determination	It is a value that indicates the proportion of the variance in the dependent variable that is predictable from the independent variable. In regression, the R^2 coefficient of determination is a statistical measure of how well the regression line approximates the real data points. An R^2 of 1 indicates that the regression line perfectly fits the data.	Distributions of inter-element spacing and orientations are plotted with the coefficient of determination being calculated for each of these plots. Since the element placement is generated in a random, but uniform manner, R^2 approaching unity is more desirable.	• R^2 below .65 was not found to occur; • The mean value for R^2 hovers around .96 and is realistic to achieve as it is the most often occurring value • The max value for R^2 hovers around .99, but occurs less often and has little effect on the other parameters.
dmin	Tells us the minimum distance between elements.	Setting a dmin allows the designer to stay within a desired inter-element distance.	• Dmin occurs most often ~.19 km. • Dmin .250 is much less common AND is requirement
RR	Isotropy	Set constraint on eigenvalue ratio (RR) to control the isotropy of the CRB, e.g. RR approaching 1. (closer to 1, more isotropic)	• In the case of X does not equal Y, RR will have to relaxed in order to meet the other constraints.
HtH	Accuracy	Set constraint on the eigenvalue product (HtH), i.e. the accuracy of estimation, smaller the area HtH, more accurate the estimation	• HtH min and mean value change very little with the change of other constraints. • A low HtH can be achieved even when sacrificing on RR.
N-M	Mission Capability	Station is Mission Capable as long as N-M>70%, where M=number of non-functioning elements. We do not model for N-M<70%	• Though N-M=6 makes meeting the other constraints more challenging, it is a requirement.

Determining whether Constraints are Realistic:

Figure 3: Began with a uniform random generator. Running the array generator 100 times yields no distinct pattern (right): X= 1000 meters, Y = 1000 meters, R^2 > .99 (both inter-distances and orientations), Dmin > 250 meters.



How can we determine realistic constraints within the tool? Testing! Additionally, each constraint was held constant to test the effect on the other constraints.

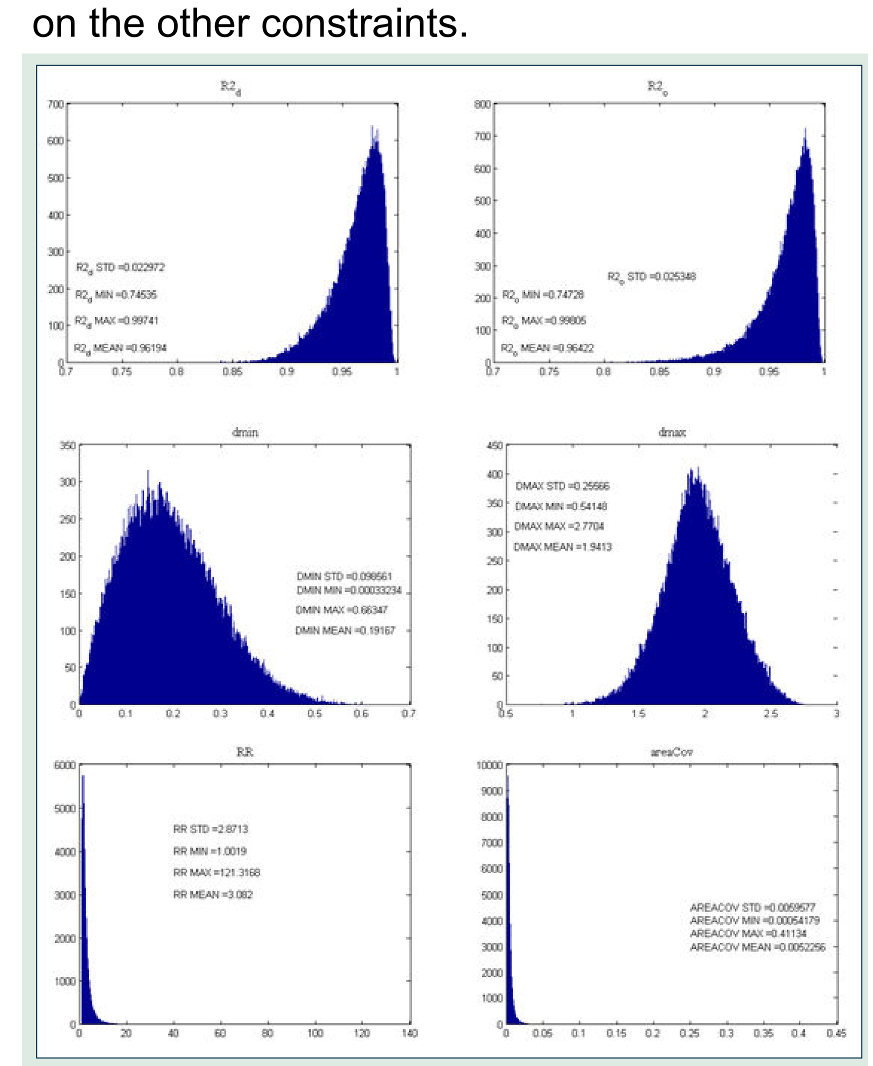


Figure 5: Example with X=2, Y=2 M=8, looped/run 100000 times

Additional Need: Inner Triangle

Detection software used by the IDC begins building detections about an inner triangle within an IMS array. A random point generator cannot guarantee an inner triangle within the generated array, so this was added to the tool.

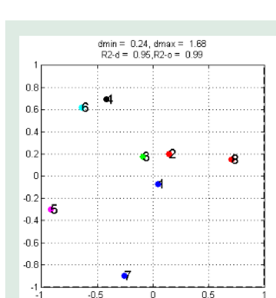
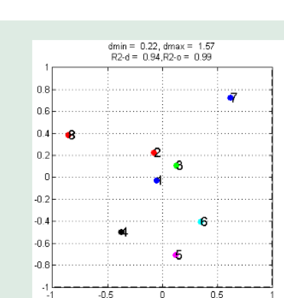


Figure 4: Center Triangle generation added to tool to assist in building detections

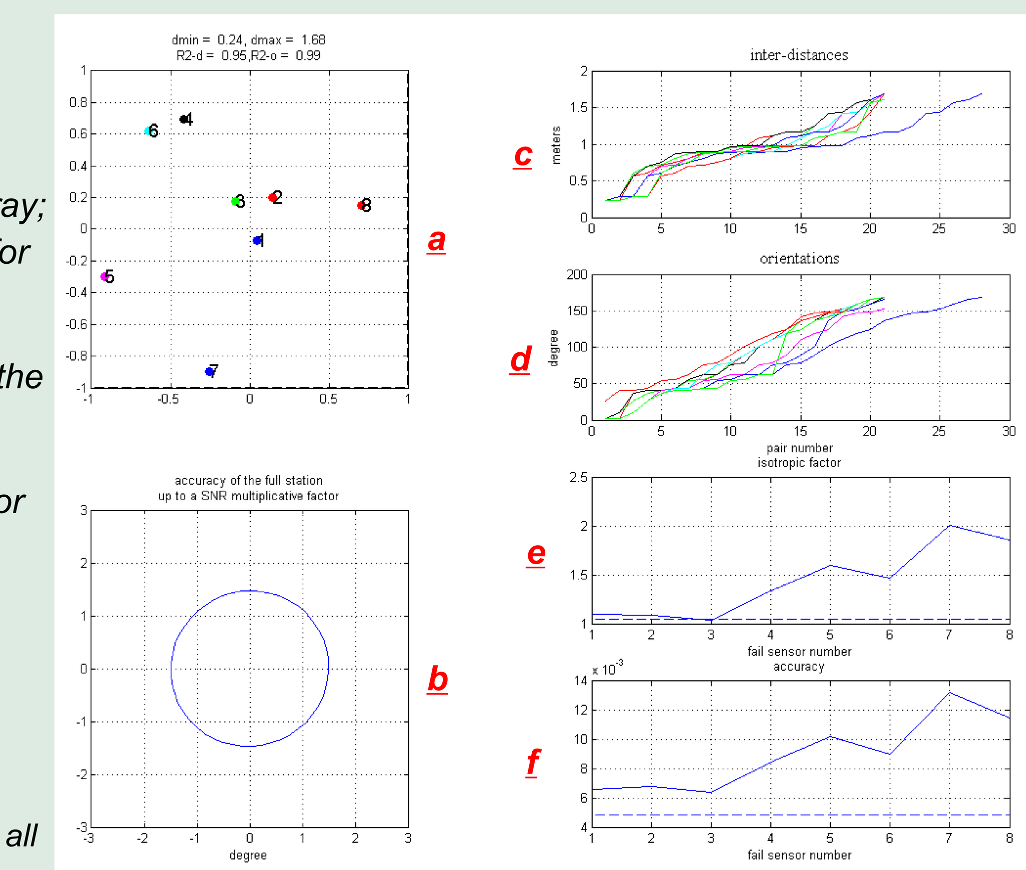


Running the Tool:

Figure 6: Graphical Output of Array Geometry Tool:

__a__: array geometry with all elements accounted for;
__b__: isotropy and accuracy of array;
__c__: inter-distances, accounting for the loss of a single element (8 different instances);
__d__: orientations, accounting for the loss of a single element (8 different instances);
__e__: Isotropic factor accounting for the loss of a single element (8 different instances);
__f__: accuracy accounting for the loss of a single element (8 different instances);

Note: Results/Plots also generated for all 28 cases of 2 elements lost/failing.



Using Tool in the field: 1) Site Assessment: Is one even able to install elements as generated theoretically on computer? 2) Record + analyze data and reassess: Too much noise? No signal? 3) Use tool to readjust array geometry as needed; 4) Repeat until satisfied.

Application: Array Geometry IS01, Argentina (2016):

A site survey for IS01, Argentina was performed July 2016 with an 8 element test-array installed on-site for a 30 day period. The geometry was created using the tool described within this poster for the case of up to 2 elements lost. Changes required on site due to obstacles were made with the tool being re-run to confirm all constraints were still met. Array geometry is then translated into geographical coordinates (Figure 7).

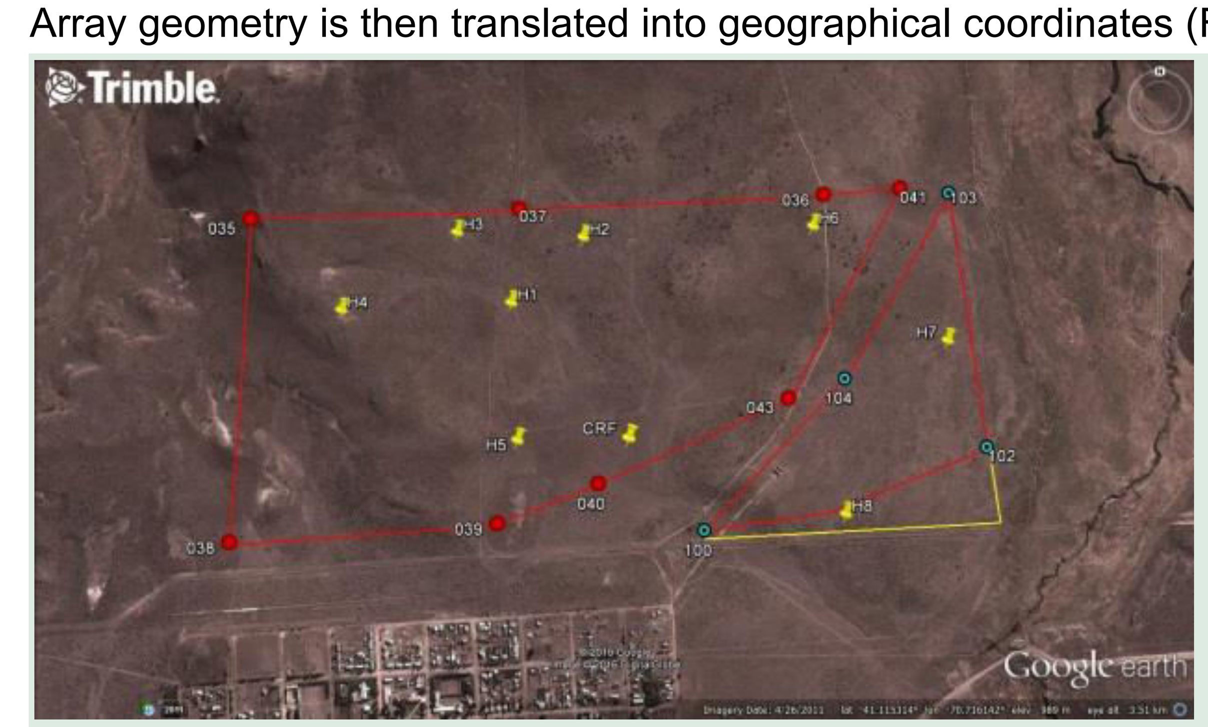
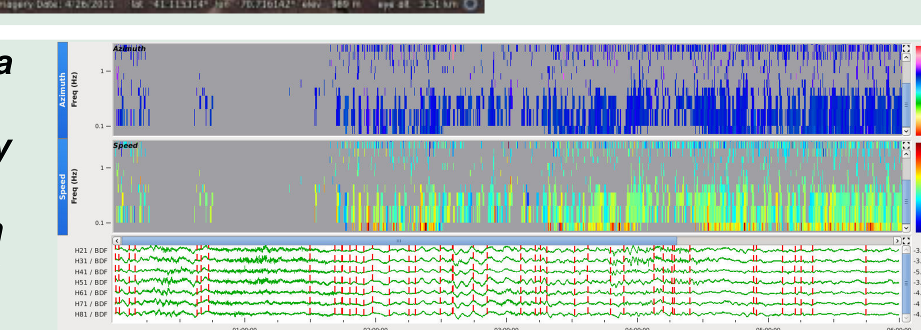


Figure 7: Several elements were moved during the first days of the survey.

H4's original location was found to be on the downslope of a hill and H5 in a flood zone – both unacceptable for a permanent installation. The elements were moved to the final locations (left) and re-checked. This was all done from a laptop while on site.

Note: The boundaries for the station were set by a defined land parcel. With IS01 being not having an area of X=Y, RR (isotropy) had to be sacrificed in order to make use of the entire array of land.

Figure 8: Data recorded during survey with final configuration generated by Tool.



Conclusions:

- Array Geometry Tool is still experimental and requires additional array deployment testing;
- Tool can be used for initial design or making assessments of current station geometry;
- Can be used when considering the addition of extra elements to existing geometries;
- <u>Tool does not replace well-chosen locations away from locally generated noise or within forested areas providing adequate wind-noise reduction</u>.