Study and Analysis of Spherical Microphone Array

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ABSTRACT
The microphones Arrays provides a wide range of applications in the field of source localization, sound reconstruction, beamforming, spatial sound field Analysis etc. using a spherical Harmonics .Speaker Identification, speech recognition, teleconferencing, Video conferencing are the commercial applicable application of spherical microphone Array. Spherical microphone Array is an open or rigid type which provides a number of advantages over single microphone system. This paper briefly describes the model of spherical microphone array, spatial sampling and present the numerical Analysis of spherical harmonics which can be used for locating the multiple sources in 3D space

Keywords
Spherical Microphone array, spherical harmonics, beamforming

1. INTRODUCTION
The spherical microphone array is a sphere at which different microphones is mounted at different position in a three dimensional geometry. The three dimensional configuration is beneficial as it can locate the sound from all directions. The far field or near field acoustic sound field is spatially sample by the microphone arrays. the microphone array not only sample the sound in time but it also samples the sound in space, different types of sampling techniques are adopted in spherical microphone array basics are: Equiangle sampling,Guassian sampling, uniform sampling.

In the field of speech processing the microphones arrays now became an emerging technology. As it is seen that from last few years microphone arrays considered for source localization, acoustic sound reproduction, speech enhancement [3-4].For about a decade the leading and trending application of microphone arrays in the area of Research is acoustic source localization.

In the literature survey the first publication in the field of spherical microphone array was founded by DuHamel [9] in 1952.He elaborated and explained the design of beampattern which is developed by the spherical harmonic equation, and later on the researcher Mayer and Elko describes spatial sound recording and beamforming [4-10]. Abhayalapa describes the higher order sound field and explained the limitation of SMA [5] while B.Rafaely the plane wave decomposition [11].L. Kumar focused on near field sound source.

For the source localization there are three different strategies is adopted: first one is the time difference of arrival (TDOA), second is maximizing the power of beamformer and last one is high resolution spectral estimation concept [6].In the first strategy it measures the delay which the time signal posses and in the second strategy microphone arrays employs the maximum likelihood estimator(ML) which focuses the beamformer to govern the various acoustic source location and gives the peak of maximum power output. The third approach is Eigen based estimation technique which estimates the location of acoustic sound by using modern beamforming techniques [6] .The Spherical microphone array configuration is of two type's rigid sphere and open sphere configuration. We are considering rigid sphere microphone arrays because of its improved numerical techniques.

The basic way for analyzing the three dimensional acoustic sound field source is inherent, as the sound field composed of superposition of plane wave [12].when the sound field infringes on the spherical microphone array it get decomposed in to plane waves which can be calculated by using spherical Fourier transform [12].The acoustic sound field is decomposed into Eigen function of orthogonal set of acoustic wave equation which is represented by spherical harmonic (eq. 13).and by the plane wave decomposition the multiple acoustic source sound can be located and analyzed by the finding the directivity of the sound field. This paper describes the theoretical equation of the spherical harmonics, directivity function, directional gain which is essential to describes decomposed plane wave for any particular direction. The simulation result uses SOFiA *sofia field analysis toolbox*[13] for finding these value .

2. SPHERICAL MICROPHONE ARRAYS
The spherical microphone arrays as it names suggest consist of array of microphones which are equally spaced and is allocated over spherical surface in an perfect geometry distribution, due to its large number of equally spaced microphones it is more advantageous over an traditional single microphone i.e. shot gun . Spherical microphone arrays give different directivity and directional gain of different acoustic sources which is used to locate the acoustic sound field.

One of the major application of spherical microphone array is the spherical harmonic decomposition [11].as in this process the position of the acoustic sound field source is located and then the beamforming is applied in order to capture the sound field from any given direction[11]. One of the important features of it is video conferencing, teleconferencing which is now widely used in the industry.

The model of spherical microphone arrays which are commonly used are "Eigen mike" shipped by Mh acoustic (fig 2.1) and is composed of 32 microphones which are correctly positioned on the surface of the spherical structure. This model perform its operations in two process first is by using digital signal processing the output of different microphones are combined to create a set of Eigen beam function and then these Eigen beams are combined to focus on the desired specific direction to locate the sound field. One of the another model of spherical microphone array is presented by Bruel&Kjaer's company which presents an acoustic camera consisting of 32 microphones and 12 optical camera(fig 2.2).hence because of its complex software design it is not commercially available in the market.

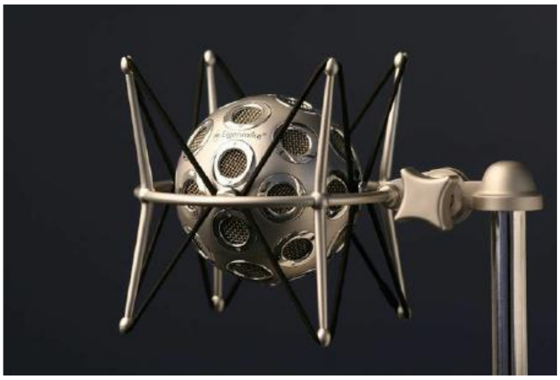

Fig 2.1 Eigen mike

Fig 2.2 Bruel and Kjaer's acoustic camera

3. SPATIAL SAMPLING

The spherical microphone arrays samples the sound field which is defined over the sphere. The spatial sampling is performed as a wave function [5]. There are three different types of sampling first is Equiangle sampling in this sampling the azimuth and elevation lines have the same number and the sample points lies at the intersection of latitude and longitude of the grid[3]. Here The harmonic order N describes the amount of microphones used for sampling and N is larger in this case. The advantage of equiangle sampling is spatial samples are taking by rotating microphones. Second and third scheme of sampling is Gaussian sampling and nearly uniform sampling .in Gaussian sampling it requires only $2(N+1)^2$ samples which is an improved scheme over equiangle spatial sampling as it provides reduced number of sample point of order N[3]. In an nearly uniform spatial sampling $1.5(N+1)^2$ samples are required where N is the harmonic order and because the small number of samples used it is best of all three sampling schemes.

4. SPHERICAL MICROPHONE ARRAY SIGNAL PROCESSING

This section describes the wave equation, spherical harmonic function Y_n^m and acoustic plane wave decomposition.

4.1 Spherical Harmonic Decomposition

The wave equation can be stated as

$$\frac{1}{r^2}\frac{\partial}{\partial r}\left(r^2\frac{\partial p}{\partial r}\right)+\frac{1}{r^{2sin^2}}\frac{\partial}{\theta\partial\theta}\left(sin\theta\frac{\partial p}{\partial\theta}\right)+\frac{1}{r^{2sin^2}}\frac{\partial 2}{\partial\emptyset 2}-\frac{1}{c^2}\frac{\partial^2 p}{\partial t^2} = \quad (1)$$

Here p is an variable of (r,θ,ϕ,t)

The solution of wave equation (eq. 1) gives four differential ordinary equations [1]

$$\frac{d^2\emptyset}{d\emptyset^2}+m^2\emptyset=0 \quad (2)$$

$$\frac{1}{sin\theta}\frac{d}{d\theta}\left[\left(sin\theta\frac{d\odot}{d\theta}\right)+(n(n+1)-\frac{m^2}{sin^2\theta}\right]\odot=0 \quad (3)$$

$$\frac{1}{r^2}\frac{d}{dr}\left(r^2\frac{dR}{dr}\right)+k^2R-\frac{n(n+1)}{r^2}R=0 \quad (4)$$

$$\frac{1}{c^2}\frac{d^2t}{dt^2}+k^2t=0 \quad (5)$$

The solution of equation 2 is represented by the

$$\Phi(\phi)=\Phi_{1e^{im\theta}}+\Phi_{2e^{-im\theta}} \quad (6)$$

Where m is an integer defined and it is continuous and periodic at $\Phi(\phi)$.

The solution of equation 3 is presented by [1]

$$\Theta(\theta)=\Theta_1 P_n^m(cos\theta)+\Theta_2\ Q_n^m(cos\theta) \quad (7)$$

P_n^m And Q_n^m are the Legendre polynomial function [1] and at the poles Q_n^m are not finite so at $\Theta_2(\theta=0)$ the solution is discarded

The solution of radial differential equation eq. 4 can be defined as [1]
R(r)=$R_1\ j_n\ (kr)+R_2\ y_n(kr)$ (8)
Where j_n and y_n are defined as Bessels functions of first kind and second kind respectively.
The spherical harmonics function is defined as $Y_n^m(\theta,\varphi)$ which is obtained by combining the angle functions in to a single function and is represented by [2]

$$Y_n^m(\theta,\phi)=\sqrt{\frac{(2n+1)(n-m)!}{4\pi(n+m)!}}\ P_n^m(cos\theta)e^{im\circ} \quad (9)$$

In equation (9) m and n are mode and order respectively and P_n^m are the Legendre polynomial of first kind and have the value of i=$\sqrt{1}$. The graphical representation of the order and degree is given in fig 4.1

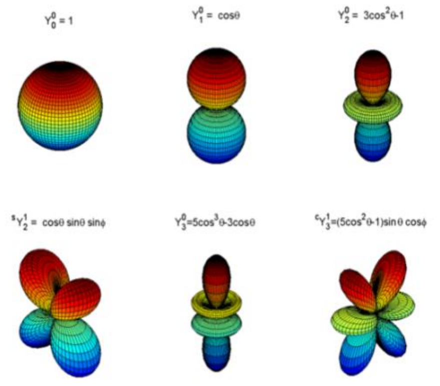

Fig 4.1 Spherical harmonics of drgree (0 and 1) and order (0 to 3)

The angular component of the wave equation is defined by spherical harmonics. Spherical harmonics function is very important term as any function on the sphere is defined by the combination of spherical harmonics [12].
The spherical harmonics function $Y_n^m$is orthonormal [1]

$$\int_0^{2\pi} d\,\phi \int_0^{\pi} Y_n^m\,(\theta,\phi) Y_{n^1}^{m^1}(\theta,\phi)^* sin\theta d\theta = \quad \delta_{nn'}\ \delta_{mm'}$$
(10)

One of the important property of spherical harmonics that any arbitrary function $g(\theta,\phi)$ on the sphere can be expanded by the combination of the spherical harmonics[12]

$$g(\theta,\phi) = \sum_{n=0}^{\infty}\sum_{m=-n}^{n} A_{nm}\, Y_n^m(\theta,\phi) \qquad (11)$$

The equation (11) is also called as Inverse Spherical Fourier transform (ISFT)where $g(\theta,\phi)$is the arbitrary function.

4.2 Acoustic Source Localization

The solution of equation (1) represented in the frequency domain as [12]

$$p(r,\theta,\phi,\omega)=\sum_{n=0}^{\infty}\sum_{m=-n}^{n}\{(A_{mn}\, j_n(kr) + B_{mn} y_n(kr)\} Y_n^m(\theta,\phi) \qquad (12)$$

$$p(r,\theta,\phi,\omega)=\sum_{n=0}^{\infty}\sum_{m=-n}^{n}\{(C_{mn}\, h_n^{(1)}(kr) + D_{mn} h_n^{(2)}(kr) Y_n^m(\theta,\phi) \qquad (13)$$

The equation (12) and (13) defined as standing wave and travelling wave respectively

hence Henkel function and Bessel function is not finite at the origin therefore our solution will only contain the first term that is equation (12) and is represented by Considering that unit magnitude wave k incident from direction(θ_l, ϕ_l) incident at a point (r,θ,ϕ)[8]

$$p(r,\theta,\phi) = \sum_{n=o}^{\infty}\sum_{m=-n}^{n} 4\pi\, i^n j_n(kr) A_{mn} Y_n^m(\theta,\phi) Y_n^{m*}(\theta_l,\phi_l) (14)$$

if we take Spherical Fourier transform of equation we get

$$p_l(r,\theta,\phi) = \sum_{n=0}^{\infty}\sum_{m=-n}^{n} pl_{mn}(kr) * Y_n^m(\theta,\phi) \qquad (15)$$

Where pl_{mn}(kr) is the coefficient given [8] .Lets us now assume that plane waves of the infinite number is coming with an strength w(k,θ_l, φ_l) and of direction $(\theta_l \phi_l)$. The directivity of different acoustic sound field is calculated and counter of the directivity used as method of source localization which is given by [8]

$$w_n(k) B_n(kr) = \lambda_{mn}(k) b_n(kr) \qquad (16)$$

The zhibin has simulated the result of equation(16) using three acoustic source incidents from the direction $1(60^o 250^o)$,$2(30^0 150^0)$,$3(120^0 150^0)$.[8].

However some error shown as the redundancy source location 4 appears on the contour plot. This can be avoided by increasing the mode of decomposition order but this can take a large numbers of microphones used for the simulation. So the Genetic Algorithm (GA) method is adopted for the optimization of spherical microphone array.

5. CONCLUSION

This paper describes the equation of spherical harmonics function and illustrates the directivity. As the contour plot of directivity captured can be used for the localization of acoustic sound field source and it is important parameter to be considered. However in the sampling techniques the harmonic order plays an important role the different techniques of sampling are shown, and the model configuration of microphone Array also explained .The spherical microphone Array should be designed such that it contains least number of microphones as microphones are cost effective this is active area of interest for the future work.

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