ISSN: 2278 – 909X
International Journal of Advanced Research in Electronics and Communication Engineering (IJARECE)
Volume 6, Issue 7, July 2017

A Review on Phase Unwrapping Techniques in Interferometry

Kamal Rani[1]*, Vikas, Ajay Shankar
Department of Physics
Guru Jambheshwar University of Science & Technology, Hisar (Haryana)

***ABSTRACT*-Since last few decades interest in automation of fringe analysis increasing more for measurements of phase shift in interferometry. Phase shift arises due to any change occurring in spatial or temporal variables of interfering waves generating a phase difference between two or more interfering beams. Phase Unwrapping is an important and challenging issue in fringe pattern analysis and plays a critical role in metrology and sensors based on interferometry. The emergence of Fast Fourier Transform technique and Phase stepping has significance for detection from fringe tracking and fringe counting point of view, but a major difficulty with such techniques has been their susceptibility to noise. Several noise-immune phase unwrapping have been proposed, but their approaches have not addressed the problems caused by large scale discontinuities such as those produced by aliasing. The phase shifting interferometer detection is the change in phase due to mechanical vibration and intensity variation by inaccuracies of reference phase shifter. Phase characteristic of function can be calculated by applying 2 π modulo operation to tangent inverse function. It can detect Lissajous display and detect continuous phase change with change in input signal. This paper provides description about phase unwrapping problem and describes fringe tracking, noise immune and fringe detection processing techniques.**

INTRODUCTION

Different phase unwrapping techniques for fringe analysis has been reviewed by Judge[1] and X. Su[2]. Most of these phase unwrapping techniques are suitable for a phase unwrapping for a static fringe system generated by interferometry, however when we have to generate phase data for inline Interferometric measurement, time required to realise these data are most crucial component. As these images are to be acquired and processed at very faster rate. We have to look into possible phase unwrapping techniques which are processed at faster rate with minimum carrier.

In this paper we are reviewing these phase unwrapping techniques which require less computation time for processing. Phase values calculated by various process lies between - π to + π, phase unwrapping algorithms necessary to recover a correct phase map. Normally phase unwrapping has implemented by addition or subtraction of 2 π offsets between neighbouring pixels. The phase unwrapping will difficult if selected region contain abrupt, noise, speckle, low modulation, speckle etc. Since last few decade many algorithms has been proposed for solving phase unwrapping problems.

In this sense, phase unwrapping is the consequence of the fringe counting problem in fringe pattern processing. When a large discontinuity occurs in the reconstruction, a 2π or multiples of 2π is added to the adjoining data to remove the discontinuity. So, the key to phase unwrapping is the reliable detection of the 2π phase jumps.

Judge and Bryanston-cross [1] have presented a review on various phase unwrapping algorithms. In this paper various algorithms are defined for phase unwrapping out of these “the phase fringe counting approach” and “minimum spanning tree methods” algorithms provide fast phase detection.

Ghiglia e*t. al.[2]* reviewed about the Cellular-automata method for phase unwrapping. Cellular automata is simple, discrete mathematical systems, offered promise of computation in a nondirectional, parallel manner. A cellular automaton was revealed that can unwrap consistent phase data in n dimensions in a path-independent manner and can automatically accommodate noise induced inconsistencies and arbitrary boundary conditions. For data with regional inconsistencies, no phase-unwrapping algorithm will converge, including the cellular-automata approach. Spik et al.[3] Investigate the cellular automata method for phase unwrapping and its implementation on an array processor. In modified cellular automata phase unwrapping algorithm linear array processor (LAP) is approx 100 times quicker. It increases the speed and cell size enlarges the two times.

Goldstein et. al. [4] described the algorithm on branch cut method in which improvement of fringe scanning algorithm. This technique is implementing to connect the residues with the branch cuts. We have to scan the interferogram until a residue is found. This algorithm is computationally efficient and proceeds faster.

Xianya Su and Wenjing Chen [5] are presented a review on reliability guided phase unwrapping algorithm. This paper contain various algorithms out of these “fast phase unwrapping algorithm based on gray scale mask and flood fill” and “phase unwrapping based on a parallel noise immune algorithm” provide fast phase detection.

Ming Zhao and Lei [6] Huang produced a technique on Quality-guided phase unwrapping technique: comparison of quality maps and guiding strategies .Quality-guided phase unwrapping is a widely used technique with different quality definitions and guiding strategies. In the presence of noise, transform-based methods are found to be the best choice for quality maps. However phase unwrapping is itself unresolved in the presence of discontinuities and hence quality-guided phase unwrapping is not sufficient.

Tomioka[7] reviewed on Phase unwrapping for noisy phase map using localized compensator. Phase unwrapping for a noisy image suffers from many singular points. Singularity-spreading methods are useful for the noisy image to regularize the singularity. This paper proposes a new phase unwrapping algorithm that uses a localized compensator obtained by clustering and by solving Poisson's equation for the localized areas. with other singularity-spreading methods.

Huntley et.al.[8] presented temporal phase-unwrapping algorithm for automated interferogram analysis. A new algorithm is proposed for unwrapping Interferometric phase maps. The approach requires that phase at each pixel be measured as a function of time. This technique is inherently robust and straight forward. The positions of the discontinuities do not change with time and unwrapped accurately.

Even though there are numerous phase unwrapping algorithms introduced in the recent years, most have shown to be capable of handling certain error sources and their success for certain phase maps only. No one single algorithm can do everything well. Some algorithms process the whole phase map at once (path independence of global algorithm), whereas others process the phase map pixel by pixel (path dependence or local algorithm).

PHASE UNWRAPPING ALGORITHM

1. Phase Fringe Counting/Scanning Approach To Phase Unwrapping

The basic procedure for analyse the wrapped phase map is known as fringe counting or fringe scanning .The recorded interferogram is filtered to remove the noise. Fringe edges may be found by an edge detection system which has a phase change threshold value of π. The horizontally scanning has a phase value 2π or less than 2π.Phase sum is added to the phase value of consecutive pixels .For good and accurate positions the vertical scanning of unwrapped phase is used. This algorithm has a disadvantage of quality of the fringe edges. There is no assurance that fringe edges are disappeared or filtered.

2. Cellular Automata Method For Phase Unwrapping

Cellular automata method is straightforward, discrete, mathematical systems that can express complex behaviour. The cellular automaton evolves in discrete time steps. The advancement of site depends only on a local neighbourhood of sites around it. The phase is unwrapped along the closed path indicated. If there is zero path difference, then all four points are said to be consistent; or else all four points are flagged as inconsistent. The method used to check for all 2 X 2 sample path inconsistencies.

The complete algorithm for 2-D automation is:

1. Every site looks at its unflagged neighbours. Orthogonal neighbours are allowed, not transverse neighbours. The phase differences between the sites of interest and each neighbour are computed (i.e. φ_{site}-$\varphi_{neighbour}$).

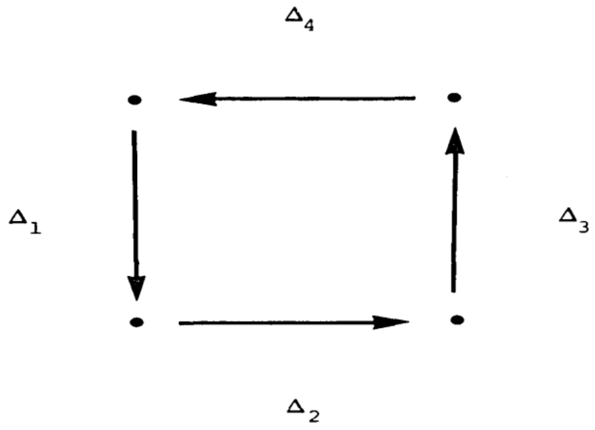


Fig. 1- Graphical representation of the method used to check for all 2 **X** 2 sample path inconsistencies.

2. To wrap the phase differences. Each neighbour's vote is equal to the integral number of 2π rad.
3. The site is changed in value by 2π rad in a direction to the accumulated strength -of –vote.
4. If none of the neighbours differs by more than π rad from the existing site, no change is made to the site value.
5. If the accumulated strength -of –vote is identically zero, the site is changed by -2π.
6. Repeat the above steps until the period-two oscillatory state is reached, then regular two oscillatory states.
7. If the phase is not unwrapped, go to the first step: otherwise terminate.

The cellular automata method has expected parallelism. It can implement on an array processor for fast increasing the speed of phase unwrapping. The drawback of algorithm is that it may require a large number of iterations to generate a end result.

Modification to The Original Cellular Automata Method

The novel cellular automata method does not resolve the phase discontinuities. In modified cellular automata phase unwrapping algorithm linear array processor (LAP) is approx 100 times quicker. Instead of four points we generate the eight neighbour's points. It increases the speed and cell size enlarges the two times. If we consider all eight directions and discontinuity has been detected instead of only four produces a more consistent result, each global iteration we have phase fringes without strike lines. This allows us to apply the phase inconsistency masking regular after each global iteration.

Large-scale phase dislocation if the part of the phase fringe disappears due to a large error in the wrapped phase, this fringe may be completely masked away or the phase is broken up into separate regions with a different stable level in all area.

3. Branch Cut Method

In this method we focus on the difficulty arising the phase measurements in a 2-D field by resolving the 2 π ambiguities related with the phase of signal. When we reconstruct the signal "phase retrieval" problem is encountered, so we have to conclude the entire phase of signals, where the phase and amplitude are discrete. The basic approach of this method is scanning it line by line and point to point. If we choose the other rule for scanning then there is inconsistency in the phase resolution. The inconsistency is an inherent property of the data. For avoiding the inconsistency, we calculate the sum of phase differences clockwise around each set of four neighbouring points. It is zero, +1,-1 cycle. The net resultant cycles as "residues" connected with four points, where plus one cycle is "plus" residue and "minus" one cycle is minus residue. The next is to connect plus and minus residues with cuts interdict the integration paths, so that no net residues can be encircled and no global errors generated.

For pixels an opposite sides of a cut there will be phase discontinuities of more than one half cycle .we have to choose a cut in such a way to minimize the total length of the cuts and thereby minimize the total discontinuity.

We have to scan the interferogram until a residue is found. If a new residue of opposite sign is found, then cut is uncharged and scan it continue to until we do not found the residue. On the other hand, if the residue has same sign as the original. Then box is moved to new residue and search until the opposite residue is located. Where the residue population is low, the location of optimum cut is apparent. Where the density is high the selected cuts can be weighed down and for the nosier region only the length of cut is minimized by try n (n-1)/2 possibilities. This algorithm proceeds faster. The uncharged residues lie on cuts, allowing no global errors.

4. Minimum Spanning Tree

In this algorithm path must traverse to minimize the phase errors between segments that gives the smallest sum of gap widths. The minimum gap width between two segments is represented by the weight of an edge connecting the corresponding nodes in the graph. The MST method, we introduce some fundamental concepts in graph theory. A graph has a set of vertices and edges, G = (V; E) vertices V = [v1; v2; . . .] and edges E = [e1; e2; . . .]. A tree is a connected graph that contains no cycles. Every pixel in a phase map has vertex and the link between two connected pixels and edge. MST is a sub graph in which the sum of the weights of all the edges in this tree is the minimum for all possible spanning sub graphs.
The algorithm accurately unwraps phase, even for images with complex structure. For some image structures, the algorithm may fail. Phase calculation using extrapolation may break down if the structure is very narrow and complicated. The system may break down if image structure is made up of widely separated segments. For determine accurate phase of widely separated segments, the shifting of the segments, from their true positions will take place.
No back-tracking is needed to maintain the accurate phase relationships between segments already considered. This specified constraint. It is also advantageous to minimize propagation of errors by traversing the tree so that the shortest edges are used first.

In the phase unwrapping application of pixel-level MST, the edge weight is calculated as the phase difference between absolute value of the two pixels that form the edge.

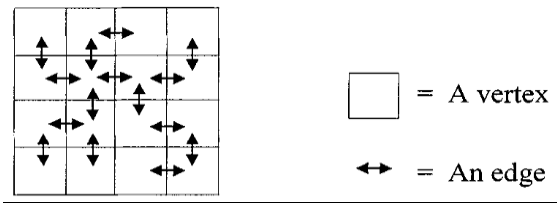


Fig. 2 - Tree in a phase map

5. Sorting by Reliability Following a Non-Contiguous Path Method (Quality-Sort)

The quality guided path algorithms depend on unwrapping the highest-quality pixels and the lowest-quality pixels. to prevent error propagation the highest reliability values unwrap first in comparison with the lowest-reliability values. Still there are some unwrapping errors can remain undetected which are propagate in a manner that depends on the unwrapping path, these algorithms are normally computationally efficient and tough in exercise. Higher reliability values produces consistent results when there are noisy areas or discontinuities present. The unwrapped pixels are positioned in the line in order. For characterizing the reliability some important parameters like intensity modulation and the spatial frequency of the fringe pattern are used.
The choice of the reliability function depends on the Design of the unwrapping path. Calculation of the reliability values of pixels depends on the second-derivative for pixels. The reliability values of edges calculated by summing the reliabilities of two pixels of which the edge links, high reliability are unwrapped first .the phase difference between neighbouring pixels, and the signal-to-noise ratio, could be selected as the oriented parameter map for phase unwrapping.
The main approach of phase unwrapping is always along the direction from the pixel with higher parameter value to the pixel with low parameter value. The algorithm is very robust. Phase unwrapping error is limited, if there is any, to local minimum areas. It can be applied for the complex fringe pattern with discontinuities.

6. Localized Compensator Method (LC)

This phase unwrapping algorithm technique solved by Poisson's equation and localized compensator obtained by clustering of the localized areas. The inconsistency standardize by local area around the singular points. The localized compensator requires two conditions. One is a source condition and other is boundary condition. Source condition related to the number of singular points. There is appropriate balancing between positive and negative singular points in the localized domain. The other condition is the boundary condition. The localized compensator must vanish on every boundary segment, and this condition is providing as an alternative.

Firstly the LC method needs to establish and after that it computes the compensators which is depending on the solution of Poisson's equation for each cluster. LC method regularizes the inconsistencies in local areas, which are cluster, around the SPs.To evaluate the compensators, integrating the result of Poisson's equation for each cluster. This technique is more accurate than the others. .Since the novel standard area outside the local area is not distorted. Even though the LC method has the drawback of computational cost. This method requires a long time cost to compute the compensators and limits the phase error for other singular points in local regions which are clusters.

7. Temporal Phase Unwrapping

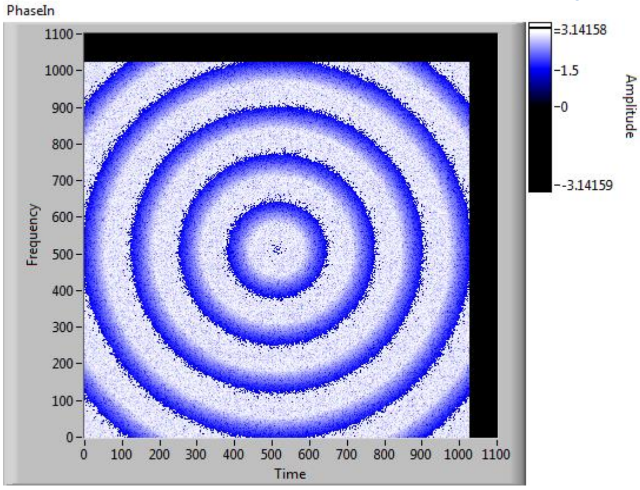
The idea of temporal phase unwrapping is to use a series of fringe maps with a distance among the fringes or small vary in fringe pitch .The wrapped phase maps has phase jump ± π to 2 π between the fringes. The problem is to add a sufficiently large number of 2 π to reconstruct the whole shape a linear sequence of fringes was used, t = 1, 2, 3, 4, ..., s fringes . Only one fringe is add between two successive wrapped phase maps and the difference of 2 π is maintained between two successive wrapped phase. The unwrapping process is then only a process of summing up the phase differences. 2 π is added or subtracted when there is a difference larger then ± π. There is a linear relationship between phase and the number of projected fringe, if one phase jump projected that means we have one fringe of wrapped phase map, when projecting two fringes the wrapped phase map it contains exactly two phase jumps.

The phase unwrapping could be carried out in real time and the phase difference is calculated from successive frames. This technique is inherently robust and straight forward. The positions of the discontinuities do not change with time and unwrapped accurately.

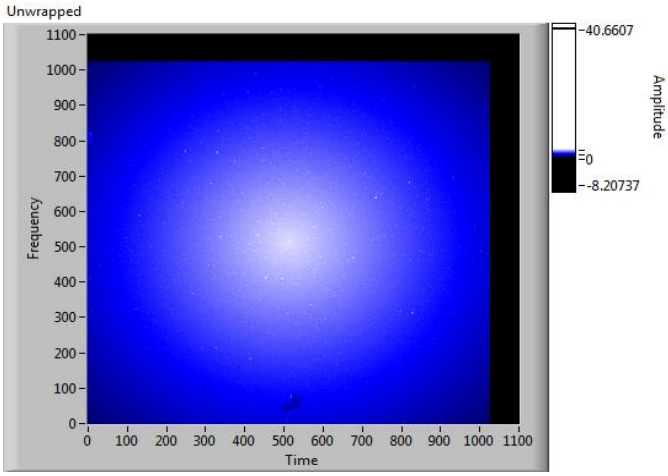
The method is relevant in which the phase map builds and where one is interested in phase changes rather than absolute phase values. It is therefore suitable for many quasi-static deformation problems, though not for faster dynamic events. Real-time phase unwrapping should also be a feasible possibility.

EXPERIMENTAL DEMONSTRATION

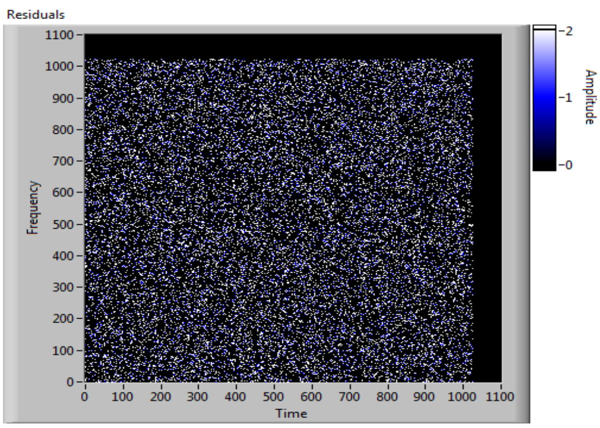
In this process we are using the lab view for simulation the different phase unwrapping techniques. The fringe pattern is generated and it is the wrapped phase map .the data that was taken from experimental demonstration related to fringe pattern. The wrapped phase data can be recovered from the phase of fringe pattern. Finally the unwrapped phase data analysed with various algorithm from the corrected wrapped phase data.



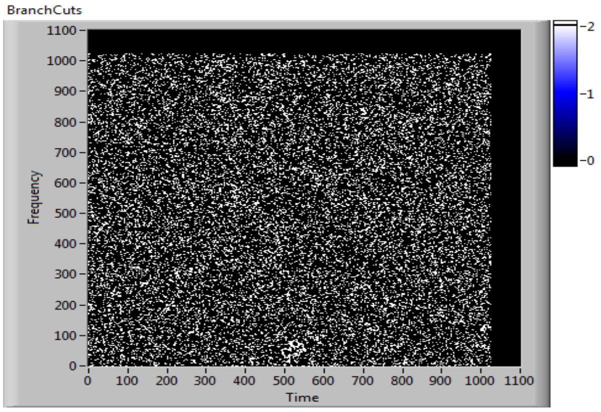
(a)



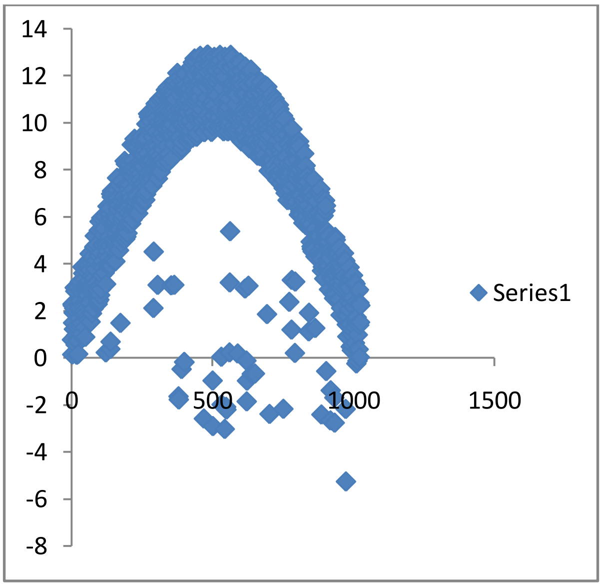
(b)



(c)



(d)



(e)

Fig.3 (a) Shows the wrapped phase map (b) unwrapping (c) residual of phase unwrapping (d) unwrapping by branch cut method (e) graph shows the positive and negative residues

We have plus residue and minus residue are present in unwrapped phase. The global error in 2-D Phase arises from residues or discontinuity in the data. In this algorithm we isolate the residue so that a satisfactory phase is obtained. Equal number of plus and minus residues gives no inconsistency .In the branch cut method no global error is generated if all residues lie on cuts.

CONCLUSION

In this article we have studied various algorithms for phase unwrapping like cellular automata method, minimum spanning tree method, quality sort method, LC method and temporal phase unwrapping method. Experimentally demonstrate the branch cut method and residual method in LABVIEW. Cellular automata method requires a large number of iterations to generate a result. Goldstein and quality sort method are very fast method. Minimum spanning tree methods minimise the propagation of errors. The LC method reduced the phase distribution and gives us accurate result for noisy phase in less time.

REFERENCES

[1] Judge & Bryanston-Cross , "A review of phase unwrapping techniques in fringe analysis "*Optics and Lasers in Engineering*, *21*(4), 199 239(1994).
[2]Ghiglia, D.C.et.al. ,"Cellular-automata method for phase Unwrapping" *JOSA A*, *4*(1), 267-280. (1987).
[3]Spik. et.al., "Investigation of the cellular automata method for phase unwrapping and its implementation on an array processor" *Optics and lasers in Engineering*, *14*(1), 25-37. (1991).
[4]Goldstein et.al. , "Satellite radar interferometry: Two-dimensional phase unwrapping" *Radio science*, *23*(4), 713-720. (1988).
[5]Su, X., & Chen," Reliability-guided phase unwrapping algorithm: a review" *Optics and Lasers in Engineering*, *42*(3), 245-261. (2004).
[6]Zhao et.al.," Quality-guided phase unwrapping technique: comparison of quality maps and guiding strategies"*Applied optics*, *50*(33), 6214-6224. (2011).
[7]Tomioka et.al. ,"Phase unwrapping for noisy phase map using localized compensator" *Applied optics*, *51*(21), 4984-4994. (2012).
[8]Huntley et. al. ,"Temporal phase-unwrapping algorithm for automated interferogram analysis" *Applied Optics*, *32*(17), 3047-3052. (1993).
[9]Miguel et.al., "Fast two-dimensional phase-unwrapping algorithm based on sorting by reliability following a noncontinuous path," Appl. Opt. 41, 7437-7444 (2002)
[10]Takeda et.al.,"Phase unwrapping by neural network". In *Proceedings of the Second International Workshop on Automatic Processing of Fringe Patterns Fringe'93* (pp. 136-141). Akademie, Berlin. (1993)
[11]Ghiglia et.al.,"two-dimensional weighted and unweighted phase unwrapping that uses fast transforms and iterative methods"*JOSA A*, *11*(1), 107-117. (1994).
[12]Towers et.al.,"Automatic interferogram analysis techniques applied to quasi-heterodyne holography and ESPI". *Optics and Lasers in Engineering*, *14*(4-5), 239-281. (1991).
[13]Ching et.al. ,"Two-dimensional phase unwrapping using a minimum spanning tree algorithm"*IEEE Transactions on Image Processing*, *1*(3), 355-365. (1992).
[14]Takeda et.al. ,"Fourier-transform method of fringe-pattern analysis for computer-based topography and interferometry". Opt. Soc. Am, 72, 156–160. (1982)
[15]Xiang et.al.. ,"A fast implementation of the minimum spanning tree method for phase unwrapping"*IEEE transactions on medical imaging*, *19*(8), 805-808. (2000)
[16]Heshmat et.al. ,"Performance evaluation of phase unwrapping algorithms for noisy phase measurements". *International Journal of Optomechatronics*, *8*(4), 260-274. . (2014).
[17]Zuo et.al.,"Temporal phase unwrapping algorithms for fringe projection profilometry: A comparative review"*Optics and Lasers in Engineering*, *85*, 84-103. (2016).


Kamal Rani, completed B.Tech in Electronics And Communication Engineering from Maharshi Dayanand University,Rohtak in 2009. Completed M.tech in Optical Engg from Guru Jambheshwar University of Science and Technology,Hisar in 2011. Currently pursuing Ph.d in Optical Engg, Dept of Physics from Guru Jambheshwar University of Science and Technology,Hisar .Her research interests include fiber based interferometer sensor.


Vikas , completed B.Tech in Electronics And Communication Engineering from GJUS&T,Hisar in 2015. Completed M.Tech in Optical Engineering from GJUS&T,Hisar2017.His research interests include phase detection of Interferometric system.


Dr. Ajay Shankar ,Completed M.tech from Delhi. Completed Ph.d from Delhi University .Currently working as an Associate Professor in dept. Of physics, GJUS&T,Hisar. Fields of Interest are Sensor, Interferometry, and Imageprocessing.