Academic education for graduates in 3-D ultrasound non-destructive testing

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ABSTRACT: The innovative and academic research ability of the graduate is one of the most important skills that are required by scientific research. The technique, 3-D Ultrasound (US), is an advanced procedure for non-destructive testing (NDT). In the 3-D US project, postgraduate students make contributions to three critical procedures: guiding phantom research, the image calibration algorithm, the 3-D location algorithm. Research was undertaken, whereby various phantoms were designed and different calibration algorithm developed. In the research conducted and outlined in this article, the preliminary 3-D location algorithm was completed and an advanced method developed. The students' innovative ability, co-operative attitude, questioning and spirit of exploration are promising qualities for the future of advanced engineering scientific research.

INTRODUCTION

Neo-liberalism has influenced academic research on education since it was proposed in the 1830s, and is extremely relevant to the innovative culture of today's graduate [1]. One of the particular neo-liberalism representatives of this type of education is John Dewey. He was an American who promoted liberalism and social action. In his core theory, he systematically analysed philosophical connotations, including these three aspects: eternal freedom, individuality and free wisdom. Thereafter, Dewey practised his neo-liberal philosophy in the American educational establishment and changed the academic values of American education. The *righteousness* of the neo-liberal is that education is one of the highest impulsive energies for improving people's thought, temperament and attitude. The neo-liberal is most sensitive and continuously reflects on the people's level of free wisdom. The core of this free wisdom is scientific spirit and the scientific method; namely, scientific experimental methods, collaborative research methods and introspective thinking. Under the neo-liberal concept, the United States has paid great attention to culturing the student's scientific spirit of co-operative attitude, questioning and exploration, and executed this idea through the whole process of education [1].

Education of the graduate in academic ability is the most important element of neo-liberalism; the innovative spirit has been at the core of academic value for graduate cultivation in the United States. The graduates' knowledge can be expanded through flexible training programmes, and the graduates' innovative ability can be promoted by a democratic instructional mode. In Germany, combining education and research, namely Humboldt's concept, is applied in university graduate education. Humboldt's concept holds that the production-study-research combination is the sustainable foundation for the graduate with academic interests. Humboldt's concept creates conditions for culturing the graduates' academic ability throughout the process of selecting research topics, selecting supervisors and selecting courses.

Japan reconstructed various graduate education programmes after a strategy of invigorating the nation through scientific and technological innovation. Their diversified form of graduate education offers various curricula, heuristic instruction and the combination of government, industries, universities and research institutions promoting the students' academic innovation. The above methods used by these countries are highly useful to other countries, such as China, in formulating their graduate education [2][3].

Engineering graduates undoubtedly need a culture of academic innovative cultivation to research and practise their engineering technology and skills. Engineering graduates have become the backbone of technical R&D and production technology [4]. So the ability and level of their academic innovation will greatly affect the ability of a country to innovate. From early 2003, some countries in Asia, including China, have implemented a graduate education innovation plan (for example by the Education Ministry), to refocus graduate education towards improving the innovation consciousness and ability in graduates' training. The research and practice for the innovation ability of graduate

students has been a hot topic in graduate education [5-7]. Engineering graduate students inevitably will be absorbed into industry. Therefore, the engineering practice ability of the graduate student is of great concern to employers and others. Often, the view is even held that engineering students should do research according to real world demands, where imagination and intellectual adventure should be controlled by the reality [8][9].

To address the above problems, various scholars have put forward different answers. In this article, the view is taken that for industrial systems influenced by many complex factors, the graduates must have the ability to gauge correctly the problems that arise and be able to provide simple and effective solutions while operating at an optimal level at all times, with the ability to organise and implement solutions. This is an important requirement, for both practical ability in engineering and for academic innovation ability. In the content outlined here, the advanced 3-D ultrasound research was divided into three: the phantom design, the calibration algorithm, and the 3-D location algorithm, according to their functions and an investigation was carried out on the plans for the cultivation of innovative ability in engineering [10][11].

ACADEMIC ABILITIES RELATED TO 3-D ULTRASOUND NDT

3-D ultrasound (US) research is an advanced field of non-destructive testing (NDT) for materials. It requires the researcher to be knowledgeable about mathematics, probability theory, computers, information and mechanical engineering. This requires that graduates in this field have an open mind, comprehensive professional knowledge and excellent ability in innovation to solve technological problems in related fields [8]. Three extremely important techniques are: the guiding phantom design, the calibration algorithm and the 3-D location algorithm. The phantom is an object model with special geometric characteristics. These geometric characteristics can provide the characteristic parameters for the calibration algorithm. The design of the phantom is the hardest technical problem in this procedure.

The calibration algorithm for a freehand probe in the 3-D ultrasound image is a technique that calibrates the spatial relationship that exists between the US image and the tracker attached to the US probe. This is fundamental research for the computerised 3-D ultrasonic image location and the US image model reconstruction. The optimised phantom design enables the scanning procedure to be finished quickly. It makes the calibration algorithm simple and accurate, reduces the influences of the US beam thickness on the precision, and improves the calibration precision and reconstruction accuracy of the 3-D US system. The calibration experiments use a magnetic locator, but the method could be suitable for other tracking devices. The co-ordinate definition and transformation relationships of the 3-D ultrasound system are detailed in Yao et al [10]. The transformation relationship is given in Equation (1).

$$T_{r \leftarrow i} = T_{t \leftarrow r}^{-1} \cdot T_{p \leftarrow t}^{-1} \cdot T_{p \leftarrow i} \tag{1}$$

In past research, elements of the procedure outlined here - the string phantom, the plane phantom and the volume phantom - were all investigated. In the authors' study outlined here, the graduates selected the string phantom, because they found that this kind of phantom can be designed in various modes and can give higher precision. In the design procedure, the authors steered the graduates toward paying more attention as to how to guide the ultrasound probe to align with the objective and accelerate the scanning speed.

The 3-D ultrasound research on string beads phantom - the Z-string beads phantom and optimisation algorithm for manual imaging co-ordinates was investigated to improve the precisions of 3-D ultrasound (US) calibration by the graduates. The phantom consists of accurate position beads and two layers of Z-string planar arrays. The beads can rapidly guide the user to align the probe accurately for imaging, so their co-ordinates are used directly in the algorithm for homologous points matching without any transformations.

The optimised algorithm incorporates the imaging points co-ordinates (mass centre co-ordinates of each point) in multiple US images that correct the manual marking co-ordinates of the imaging points. The calibration parameters are calculated by the matching of homologous points in the image and the tracking device and, then, the 2-D US image can be converted into 3-D US co-ordinates. The results show that this method can simplify the calibration algorithm, reduce the influences of the US beam thickness on precision and improve the calibration precision and reconstruction accuracy of the 3-D US system. The calibration experiments are demonstrated with a magnetic locator, but the method could be suitable for other tracking devices.

The 3-D ultrasound research on the cross string phantom - to improve the calibration precision, a method based on a grid string phantom and rapid algorithm for co-ordinate transformation was investigated by the graduates in this study. It accurately defines the spatial relationship between the US image plane and an external tracking device attached to the US probe. The phantom consists of two layers of grid-string planar arrays. The cross of the strings can rapidly guide the user to align the probe accurately for imaging; the cross co-ordinates are used directly in the algorithm for homologous points-matching without any transformations. The calibration parameters are calculated by matching the homologous points in the image and the tracking device and, then, the 2-D US image can be converted into 3-D US co-ordinates. The results show that this method can accelerate the speed of the calibration, simplify the calibration algorithm, reduce the influences of the US beam thickness on the precision, and obtain the normal calibration precision and reconstruction accuracy of the 3-D US system.

Ultrasound image calibration algorithm - with the development of ultrasonic technology, ultrasonic testing has become one of the main detection technologies in the medical, industrial and aerospace industries, etc. There is a systematic and complete experimental and theoretical analysis for ultrasonic non-destructive testing, such as setting parameters, the guide phantom, matching probe, scanning experiment, image denoising, image analysis, algorithms, analysing results and 3-D reconstruction. The purpose is to analyse directly the wear and morphological variation of things or objects, and to gain the location parameter. The calibration algorithm is important in this process. Both the string beads phantom and the cross string phantom have the same image calibration algorithm; namely, a similar triangle algorithm. The similar triangle algorithm is based on the guide phantom. The co-ordinates of the imaging points of the string or beads in the ultrasound image were obtained by the graduates through their self-developed software. Then, the ratio of the distance between the left points and centre points, and that between the centre points and the right points was obtained.

This ratio is the same as that calculated by the homologous points in the phantom. Therefore, the homologous points' co-ordinates can be calculated through the similar triangle relationship. In this research, the graduates implemented the traditional calibration algorithm, and also proposed the repeated selection of the imaging points co-ordinates in the ultrasound image based on the two phantoms; ultimately, applying the least squares matching algorithm to the homologous points in the phantom system and the image system to obtain the transformation relationship of the two co-ordinate systems $T_{p \leftarrow i}$. Then, they used $T_{p \leftarrow i}$ to transfer the imaging points to the tracker (receiver) co-ordinate system. The least squares matching algorithm was applied to the homologous points in the image co-ordinate system and the tracker (receiver) co-ordinate system to calculate the transformation relationship of the two co-ordinate system $T_{r \leftarrow i}$. This is detailed in Yao et al [10], see Function (2).

$$\min_{R,p} \sum \left\| P_r - (sRP_i + p) \right\|^2 \tag{2}$$

The 3-D location algorithm - ultrasonic non-destructive testing is used widely in interior materials testing, two-dimensional ultrasound imaging is used where there are space limitations, investigators who need to examine defects of the brain in three-dimensions. A three-dimensional ultrasound provides more detailed location information and visual imagery compared to two-dimensional ultrasound. Prior to use, the three-dimensional ultrasound system must be calibrated to determine the ultrasound image plane co-ordinate system and is attached to the ultrasound probe positioning device for co-ordinate conversion. The graduates developed the 3-D location algorithm using the ultrasound image calibration results. They used the calibration results to transform all the pixels in the ultrasound image into the 3-D co-ordinate system. Although their research in this field is preliminary, they have made encouraging progress toward enabling further research.

$$P_t = T_r^t \cdot T_i^r \cdot P_i \tag{3}$$

RESULTS AND DISCUSSION

The graduates in the study outlined here selected the GE Phasor XS instrument by which to gain fuzzy image points in the experiments. Combined with the series of processing and algorithm steps proposed in this article, they provided a theoretical basis to determine the co-ordinate parameters for 3-D reconstruction.
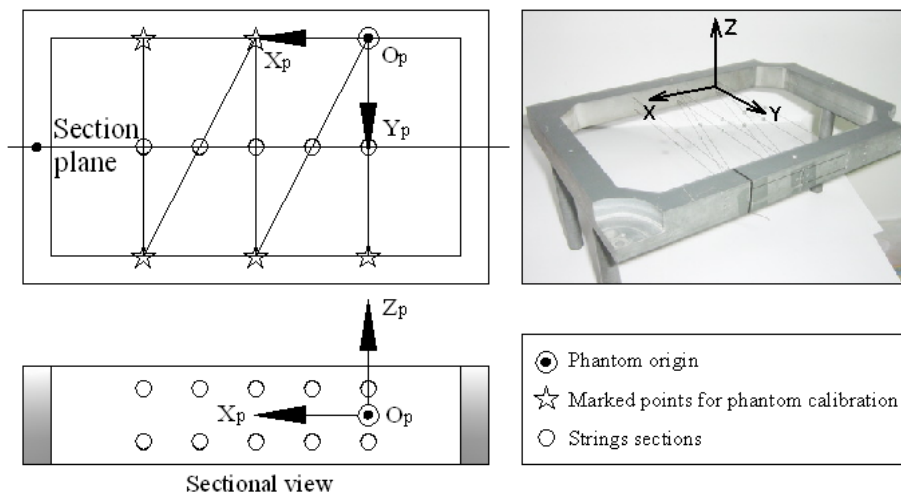

Figure 1: String beads phantom construction.

String beads phantom design - the four (4) verticals (holes) of the Z-string in the same wall as the phantom origin and the three (3) up-down stagger verticals (holes) in the opposite wall are the marked points (the *star* positions marked in

Figure 2). All co-ordinates of the marked points (holes) in the phantom co-ordinate system P_p are given when the phantom is designed. The needle attached with the tracker (magnetic receiver) is placed in the holes (Figure 1); using a magnetic tracking algorithm $T_{t \leftarrow r}$ and the co-ordinates of these holes in the receiver are calculated, marked as P_t. A least-squares fit to P_p and P_t is applied to calculate $T_{p \leftarrow i}$. Details are in Yao et al [10].
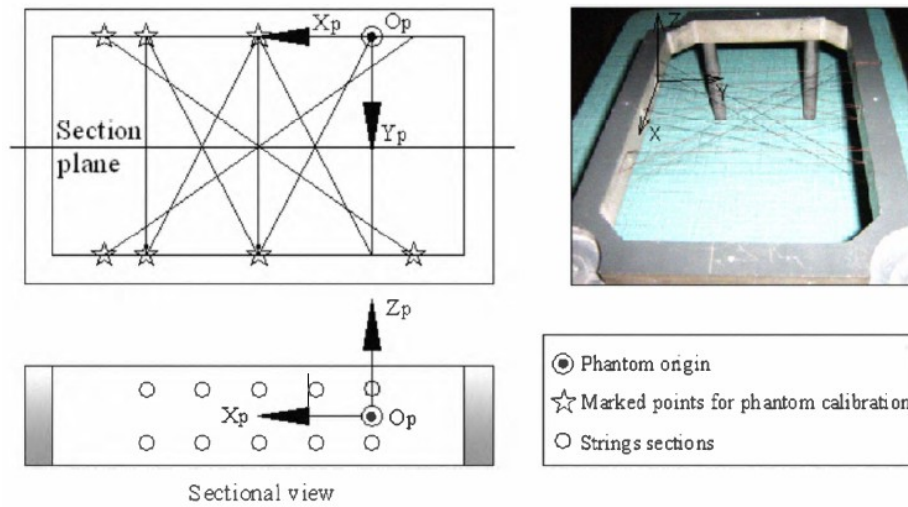

Figure 2: Cross string phantom construction.

Cross string phantom design - the cross string phantom consists of a grid string of planar arrays, marked points and phantom frame. The cotton strings constructing the grid planar arrays are 0.3 mm in diameter. Due to their elasticity, they can be tightened to maintain the precise position of the strings both in dry and wet conditions. The cotton strings pass through the holes, 1 mm in diameter, on both the front and back walls and form two layers of grid strings arrays with three (3) or four (4) cross points in the centre of the phantom, as is presented in Figure. 2. Each grid string layer is parallel to the string plane of the phantom co-ordinate system. Phantom construction and the phantom co-ordinate system are shown in Figure 3. The marked points (the star markings in Figure 2) are four (4) verticals (holes) of the all grid-string in the same wall as the phantom origin and three (3) up-down stagger verticals (holes) in the opposite wall. The coordinates in the phantom coordinate system are determined when the phantom is designed. The location of the needle tip in the holes, the $T_{p \leftarrow i}$ were calculated.
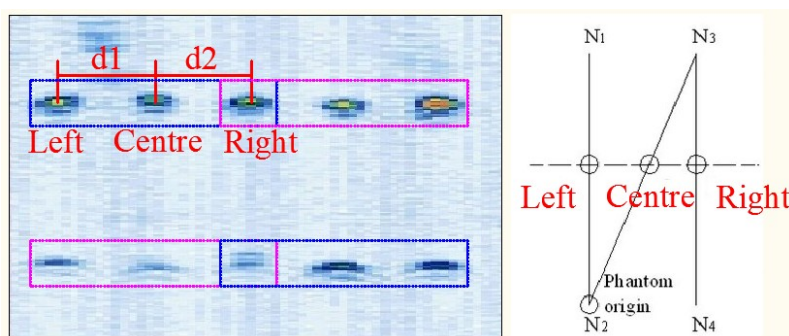

Figure 3: Ultrasound image calibration algorithm.

Calibration algorithm - in this research, the graduates implemented a calibration procedure by the similar triangle algorithm as mentioned above, and they used another method that selected the 10 imaging points repeatedly. The 10 point co-ordinates in the ultrasound image are produced through the graduates' self-developed software; ultimately using the $T_{p \leftarrow i}$ to transfer 10 imaging points to the tracker (receiver) co-ordinate system. A least squares matching algorithm was applied to the homologous points in the image co-ordinate system and the tracker (receiver) co-ordinate system to calculate the transformation relationship of the two co-ordinate system $T_{r \leftarrow i}$.

These two methods were applied, both to the string beads phantoms and the cross string phantom and the results. The results are shown in Table 1. In the traditional method, any angle scanning can be used, so that in any plane, the string bead phantom scanning speed is the highest. But its precision is not high. The string beads phantom's calibration

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precision is the same as the cross string phantom and the cross string phantom is higher than either. The calibration algorithm is superior to the traditional algorithm, both on speed and the precision. The 3-D location algorithm has the same speed and precision as the traditional algorithm.

Table 1: Calibration results for different algorithms.

	String bead phantom		Cross string phantom		Calibration algorithm		3-D location algorithm	
	Speed	Precision	Speed	Precision	Speed	Precision	Speed	Precision
Traditional algorithm	H	M	H	M	M	M	S	S
Graduate algorithm	M	M	M	H	H	H	S	S

Note: L: low   M: middle   H: high   S: same

CONCLUSIONS

Based on the research on graduate behaviour carried out on the 3-D ultrasound project, the following conclusions are drawn:

1) Graduates can complete high-tech, cutting-edge research work.
2) Team co-operation benefits the graduate in promoting innovation and creative inspiration.
3) The graduates' had shortcomings in their academic research ability in the design of the experiments and the analysis of the results, which were not sufficiently scientific, thorough and comprehensive. This problem may be due to the graduates' lack of practical experience. This statement will be verified in researched by the authors in the next stage of this process, by adjusting the training plan to improve abilities in experimental innovation.
4) During the research, the instructor can offer opinions to the graduates, but must be limited regarding the direction of their research. The opinion offered must not be too detailed, otherwise the graduates' innovative ability will not be successfully developed.

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