The ultrasonic pulse echo technique applied to concrete and steel structures

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Abstract

Depending on the information required, various technologies must be applied when investigating reinforced concrete structures. In particular, there are specific types of fault such as delaminations and voids that are most suitably detected using ultrasonic techniques. However, it is quite often the case that access to such structures is limited to a single side, making traditional ultrasonic techniques impossible. Also, traditional ultrasonic techniques do not provide depth information about the location of internal defects, unless a huge amount of measurements are made and sophisticated software is used to create tomograms. The ultrasonic pulse echo technique enables users to collect this information even when access is limited to a single side. The major drawbacks to the technique have been the effort required in making scans when compared to electromagnetic techniques, and the subjective nature of data interpretation. Recent research carried out has sought to use intelligent algorithms to improve speed and precision of large-scale scanning, and also to rely on artificial intelligence for object recognition in a scan. Furthermore, a method is proposed to use information collected with other technologies to increase depth accuracy. The current state of this research is presented in this paper with real-world examples, showing achievements to date and indicating where future development is required.

1. Introduction

Imaging of concrete structures is a relatively difficult task due to the inhomogeneous nature of the material being scanned. Nevertheless, it is a necessary task for obtaining complete information about the structure under investigation. Recent developments in various technologies such as pulse echo (PE), ground penetrating radar (GPR) and eddy current (EC) are helping to provide engineers with better information. However, the analysis of the collected data is not always easy. The rapid increase in computing power available in tablet computers means that it is now feasible to start using artificial intelligence (A.I.) features to support non-destructive testing applications on site.

2. Intelligent algorithms to improve speed and precision of scans

2.1 Using A.I. algorithms to improve speed and precision of scans

PE images are made up of individual B-scans. A typical array transducer is around 20 to 30 cm wide. In the examples that follow, the Pundit Live Array transducer by Proceq was used to create the images, with each B-scan being 21 cm wide. Generating larger images requires the stitching of multiple images together. B-scans may also be overlapped to remove edge effects, which are particularly noticeable in shallow objects.

Such large-scale images can be up to several meters in length. As such, their quality depends on the accurate placement of the transducer throughout the data collection process. Consequently, a large effort is required to generate accurate large-scale images. Current research is considering methods to reduce the time needed to collect data and, ideally, to remove the user's influence on the accuracy of transducer placement.

The first method which has been shown to provide good results involves the use of a calibrated tape placed on the structure under investigation. Thanks to A.I.-enabled computer vision algorithms, a camera on the transducer detects exactly where the transducer is in relation to the tape. This information is then used to accurately position the current B-scan within the overall image being captured. Figure 3 shows examples of large scale images created with and without the use of A.I. to position the transducer.

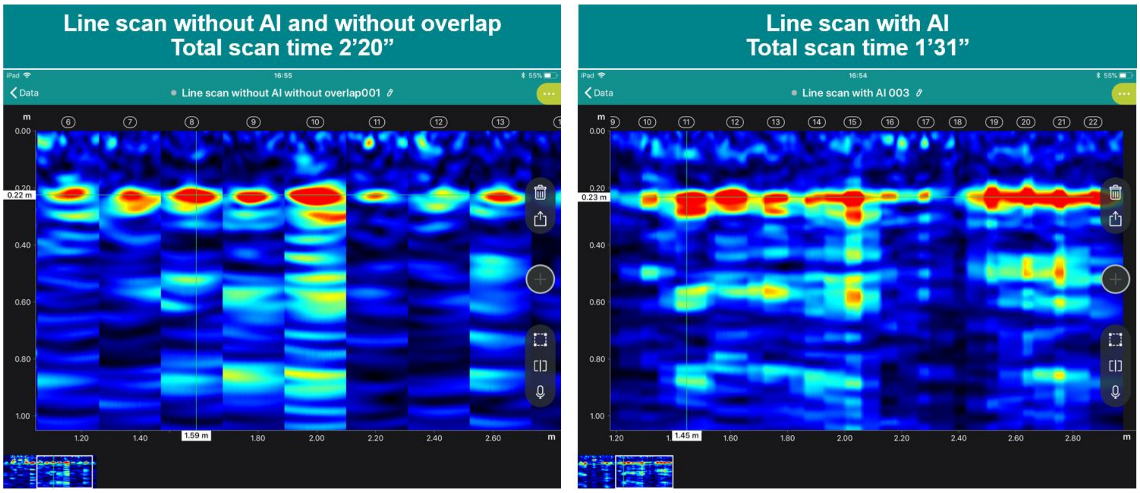

Figure 1. Large scale scans with and without the use of intelligent positioning. In each case shown here, the total scan length was close to 3 meters.

The image on the left was created without any overlap of the individual B-scans. While this method is the fastest, as it requires a smaller number of scans, the gaps in the back-wall echo caused by edge effects can be clearly seen. In contrast, the image on the right was created with A.I. detection of the precise position of the transducer along the tape. Thanks to the overlap, there are no gaps in the back-wall echo – and yet, despite the overlap, the entire scan took just over half the time required for the image on the left.

2.2 A.I.-assisted object recognition

The interpretability of generated images is a further aspect that needs to be improved, if concrete imaging technologies are to become more widely accessible. This need for improvement applies to all imaging technologies; PE, GPR, EC, and impact echo.

To this end, current research and development is focused on using A.I. techniques to identify and categorize the objects detected in the images resulting from concrete scanning. Such "A.I.-Assist" technology is currently in an early stage. However, initial results are promising, and clearly show that this is the way forward.

The back wall of the concrete structure being investigated is the largest object in a PE scan. It is also one of the objects of major interest in practical cases, as it is used to determine the pulse velocity. Moreover, a common application of PE technology is the measurement of thickness variations of a concrete structure. A good example of this is the on-site evaluation of the thickness of tunnel linings.

In our research and development of A.I.-assisted object recognition, therefore, the automatic detection of the back wall served as the litmus test of technological feasibility. The two examples shown in figure 2 show what can be currently achieved.

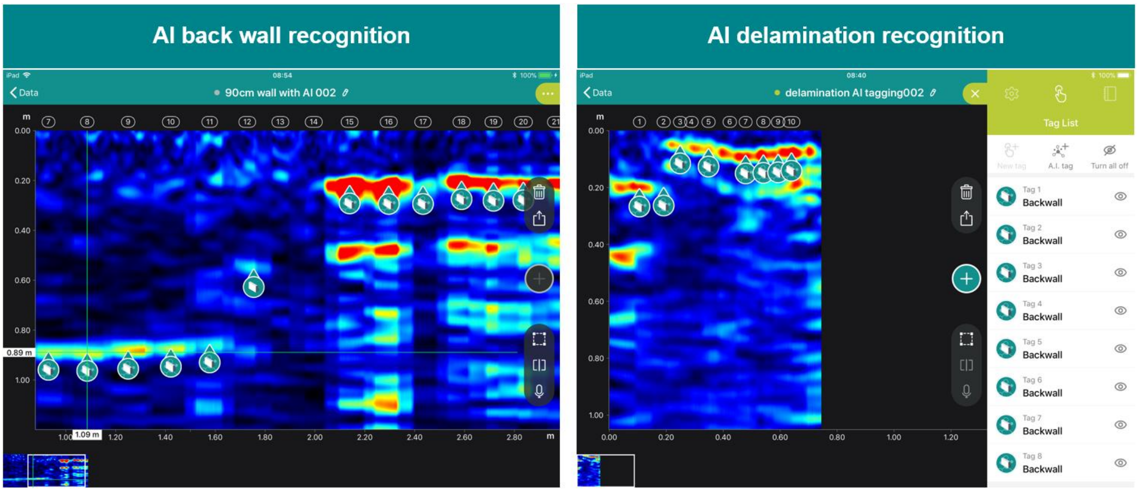

Figure 2. A.I.-assisted object recognition. The B-scan on the left shows tagging of a back wall with a step change of 70 cm in thickness. The B-scan on the right shows tagging of a large delamination.

The B-scan on the left is of a concrete wall with an initial thickness of 90 cm, which abruptly changes to approx. 20 cm. The green tags on the screen indicate objects that are detected automatically by the A.I. algorithm. The results are quite convincing: the wall at 90 cm depth has been correctly identified, which is also true for the wall at 20 cm depth. Furthermore, the multiple echoes below the region of 20-cm thickness have been correctly ignored by the algorithm.

The B-scan on the right shows another case of interest, because it highlights one of the limitations of the current state of development. This scan shows a slab which is 20 cm thick, containing a large delamination that spans depths between about 10 and 15 cm. The detection algorithm has misidentified this large object as a back wall, as it cannot differentiate between a back wall and a delamination based on the information used. Of course, this should be a simple matter for the user to differentiate, assuming he or she has knowledge of the actual thickness of the concrete structure under investigation. It does mean, however, that the interpretation of the image still requires user input.

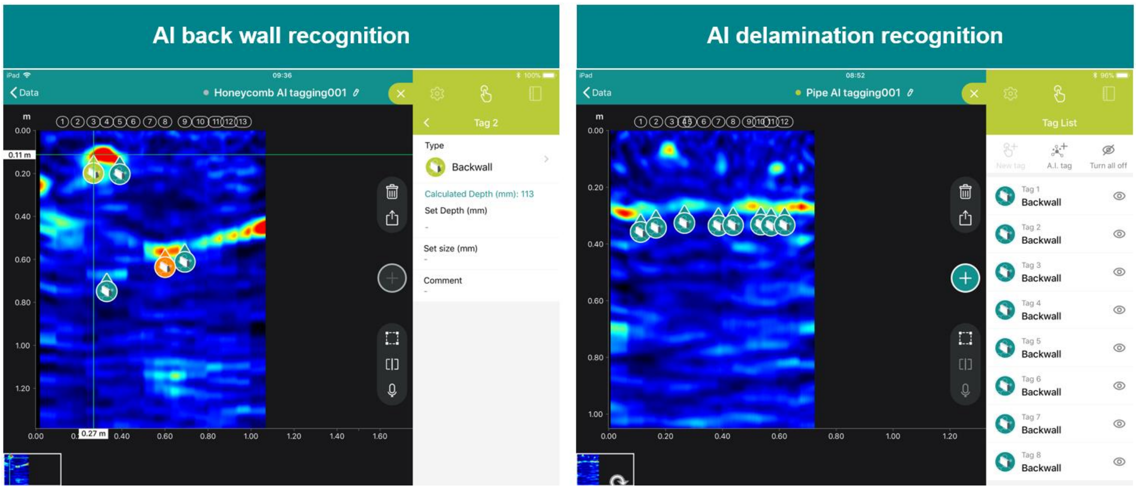

Figure 3. A.I.-assisted object recognition of smaller objects. The B-scan on the left shows a scan of a V-shaped concrete element with honeycombing close to the surface. The B-scan on the rights shows a concrete element, 30 cm thick, with three hollow pipes.

Figure 3 shows some examples of the current algorithm applied to smaller objects. In the B-scan on the right, the concrete structure features a sloping back wall. At its thickest point, the back wall has been recognized and tagged correctly. This is not the case as the scan moves to the right and the thickness decreases. To the left of this scan, there is observable honeycombing at a depth of 11 cm. This has been identified correctly – still, the algorithm cannot differentiate this from a back-wall reflection. This case would again require user input to interpret correctly and tag accordingly. The B-scan on the right is a concrete slab, 30 cm thick, with three hollow pipes. The back wall has been correctly recognized; however, the pipes cannot be detected by the algorithm.

Currently, the algorithm works by analysing the echoes in an individual B-scan. Clearly, results would be improved if it also analysed the data of the entire scan. For smaller objects, there is an added challenge of automatically distinguishing between metallic objects (such as rebars) and non-metallic objects (such as hollow pipes and voids). To this end, it is necessary to utilize information regarding the presence (or not) of a phase inversion of the signal. Algorithms for detecting phase shifts have been successfully demonstrated (1), but are yet to be integrated in automated object recognition systems.

2.3 Combination with other technologies for enhanced depth accuracy

2.3.1 Pulse-echo depth accuracy

PE instruments measure the transmission time of echoes reflecting from the boundaries between two materials. The depth of the object is then calculated using the transmission time and the pulse velocity. As expected, an accurate determination of the pulse velocity is critical to producing accurate images.

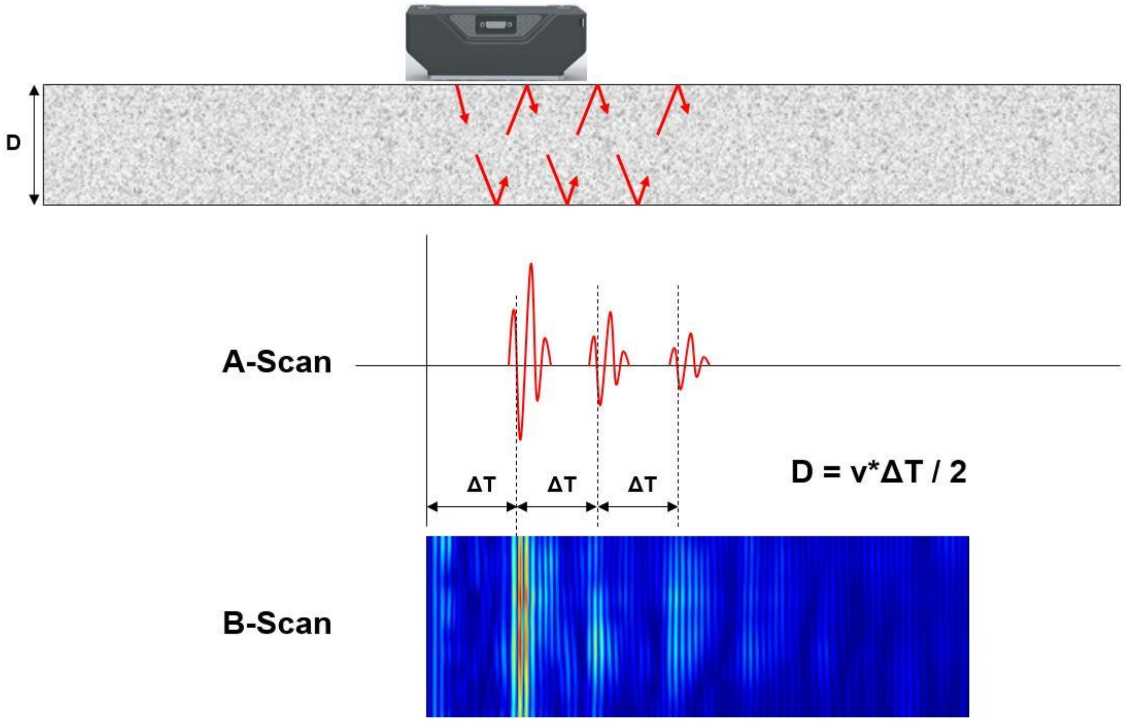

Figure 4. Pulse-echo measurement principle. The depth is calculated from the transmission time and the pulse velocity

2.3.2 Alternative methods for pulse-velocity determination

Two methods are commonly used to estimate the pulse velocity. The first is based on measuring the transmission time of a wave travelling at the surface between two or more transducers a known distance apart. This is the same principle as the method specified in ASTM C1383 (2) for determining the P-wave velocity of an impact-echo system.

However, this method has a known limitation: there can be large differences between the surface-wave velocity and the wave velocity through the concrete volume. Nevertheless, this method must be used when there is no information about the actual thickness of the element being tested.

The second method uses a known thickness to calibrate the pulse velocity. This method gives the most accurate results. Analysis of data collected by the German Federal Highway Authorities (3) suggests that the expected accuracy of the pulse-velocity calibration using this method is within ±2%.

2.3.3 Possible usage of other technologies for pulse-velocity determination

A third possibility is now being investigated: utilizing the depth of other objects inside the concrete volume (such as pipes and rebars) to calibrate the pulse velocity. It relies on the depth of the object in question to be determined with a reasonable degree of accuracy. An example can be seen in figure 5.

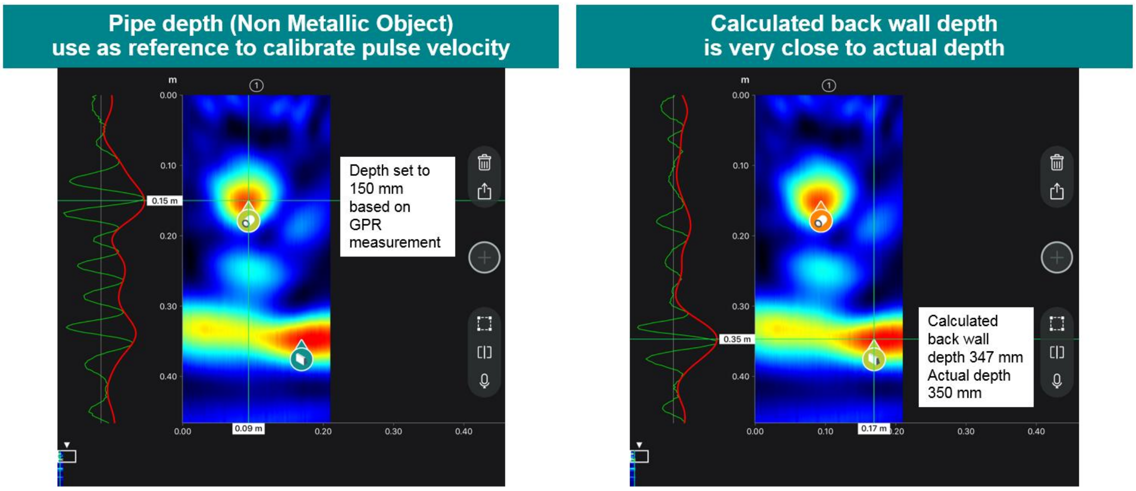

Figure 5. Pulse-velocity calibration using a reference pipe depth. The depth of the pipe must be determined by another technology (in this case, GPR). This is used to calibrate the pulse velocity, which in turn is used to calculate the depth of other objects, such as the back wall

In this example, the depth of a hollow plastic pipe was determined using measurements with a handheld stepped-frequency continuous-wave GPR device. The pulse-echo B-scan on the left shows the position of the pipe. A tag, used to mark its position, can be aligned very accurately to the peak of the A-scan using a cursor. Once this tag has been set, it can be assigned to the depth determined by the GPR measurement. This has the effect of setting a new pulse velocity setting for the scan.

The B-scan on the right shows the back-wall tag, also aligned to the A-scan peak. In this case, the calculated depth was very close to the actual depth. Of course, the usefulness of this method depends on the accuracy with which another technology can determine the depth of the reference object. In the case of GPR this may be ±1 mm under ideal conditions that cannot be guaranteed, but realistically within ±5 mm / ±5%. Furthermore, the object used as a reference must be detected by both technologies (e.g. PE and GPR). In the case of PE and GPR, this represents a challenge for most narrowband impulse GPR devices, due to their limited penetration depth.

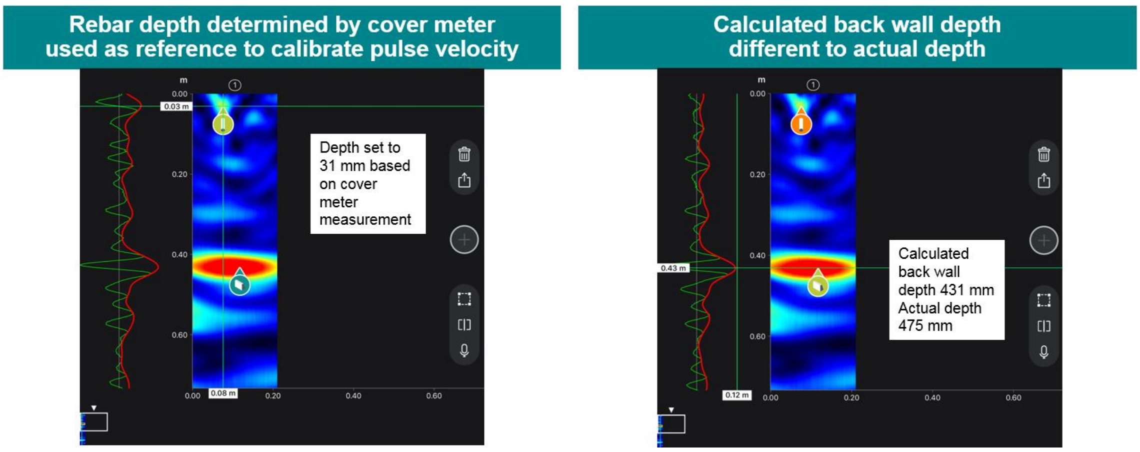

Figure 6. Pulse-velocity calibration using reference rebar depth. The depth of the rebar is accurately determined using a cover meter. This is used to calibrate the pulse velocity, which in turn is used to calculate the depth of other objects, such as the back wall

Another option would be to use a rebar as a reference object, as the depth of rebars can be very accurately determined using EC cover meters within the first 12-15 cm within a concrete volume. An example of this can be seen in figure 6.

In this example, the calculated back-wall depth deviates by about 10% from the actual value. The main reason for this is that rebars are typically close to the surface; however, the pulse velocity in the first few centimetres of the concrete volume is known to differ from the pulse velocity within the concrete volume (4). This may lead to discrepancies when this method is used to determine the depth of objects deeper within the volume.

Nevertheless, this still a viable method, as it delivers results significantly superior to the surface-wave pulse-velocity estimation. For reference: on the same object, the pulse-velocity estimation by surface wave resulted in a back-wall depth of 351 mm, a significant deviation from the actual value of 475 mm.

3. Conclusions

The examples presented in this paper clearly demonstrate that A.I. features can already be very useful in assisting users with the interpretation of images created with PE technology. Further research and development is required for a) improving the detection of smaller objects, and b) automatically and reliably differentiating between object types.

The techniques here are applied purely to PE. However, it is also clear that no single technology can master all challenges in real-world applications and use-cases. As such, we expect that future combinations of PE with other concrete imaging technologies will further improve the captured data and resulting images .

Finally, we foresee that further development of accurate measurement equipment together with A.I. features and data fusion will increasingly make the choice of technology a moot point for the end-user, who will become increasingly focused on the quality of concrete imaging and the resulting insights from the inspection, rather than on the strengths and weaknesses of each technology and his own data-interpretation skills.

References

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