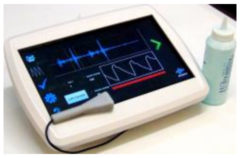
ARTSENS: An Easy-to-Use, Image-Free Technology for Arterial Stiffness Evaluation and Vascular Screening



"Collaboration with NI through their Planet NI program, allowed us early access to SOM that is powering the development of ARTSENS Mobile. The SOM helped us quickly leverage the extensive R&D work that was performed using LabVIEW and port that to an embedded system so we could develop a portable, field deployable product within a very short time."
- Dr. Jayaraj Joseph, Healthcare Technology Innovation Centre, IIT Madras (https://htic.iitm.ac.in/)

The Challenge:
Affordable technology for large scale vascular screening Arterial Stiffness and Cardiovascular Diseases.

Read the Full Case Study

The Solution:
ARTSENS: An easy to use image free technology for arterial stiffness evaluation and vascular screening.

Author(s):
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Planet NI
A National Instruments Program

Healthcare Technology Innovation Centre (HTIC) of IIT Madras is an R&D centre established through a joint initiative of IIT Madras and Department of Biotechnology (DBT), Government of India. Since its inception in 2011, HTIC has evolved into a unique and leading medical technology innovation ecosystem in the country and brings together more than 20 medical institutions, industry, and government agencies. These organisations collaborate with HTIC to develop affordable healthcare technologies for unmet clinical needs. HTIC delivers innovations and technologies that reach the field, enabling business and benefitting society.

Figure 1. Overview of HTIC Ecosystem and Technology Development

Cardiovascular diseases (CVD) cause the most deaths globally, with nearly 17.3 million deaths in 2008 and the number expected to increase to 23.3 million by 2030. CVD affects nearly 10 percent of the Indian population, with nearly 45 million suffering from coronary artery disease. India has seen a significant shift in disease burden from communicable to noncommunicable diseases (NCD) over the last few decades, with CVD accounting for half of all deaths from NCDs. With such a huge disease burden and limited availability of specialists and healthcare resources for treatment, an effective strategy for disease control would involve large-scale screening to triage at-risk subjects for early intervention and disease prevention.

State of Art and Limitations

Stiffness of artery walls is an established marker of vascular health with stiffer arterial walls often observed in subjects with vascular problems. Arterial wall stiffness has proven utility in early detection of vascular diseases and risk stratification. However, state of art technology for noninvasive evaluation of the vessel wall properties typically require an imaging system such as ultrasound to visualize arterial geometry and an expert radiologist to capture correct images and identify arterial anatomical features for performing stiffness measurement. The requirement of expensive technology and extensive technical expertise to use that technology limits wide-spread use of image-based arterial stiffness measurement in clinical practice.

Clinical Need

There is an unmet need for an affordable, easy-to-use technology to noninvasively measure arterial stiffness in an automated manner, which could be used by general medical practitioners and health workers. Such a nonexpert operable device, which performs automated measurement, would mitigate the skill barrier and also reduce the time taken for test, thereby making it suitable for large-scale cardiovascular screening.

ARTSENS stands for ARTerial Stiffness Evaluation for Noninvasive Screening, and is an image-free technology to noninvasively investigate arterial wall dynamics and perform automatic measurements of arterial stiffness with no operator inputs. ARTSENS utilizes a high-frequency ultrasound transducer to capture artery wall dynamics. The transducer insonates the region around the carotid artery and also receives the echoes reflected by different anatomical structures in the sound propagation path. Intelligent signal processing algorithms, based on advanced mathematical methods and developed after extensive research into the echo signal characteristics, help accurately identify arterial structures and track wall motion to measure arterial distension, with no operator inputs. The system can give a measurement of arterial stiffness within a minute of placing the probe over the neck of the subject because of the robust artery detection, wall tracking, and on-line distension wave analysis techniques developed in HTIC.

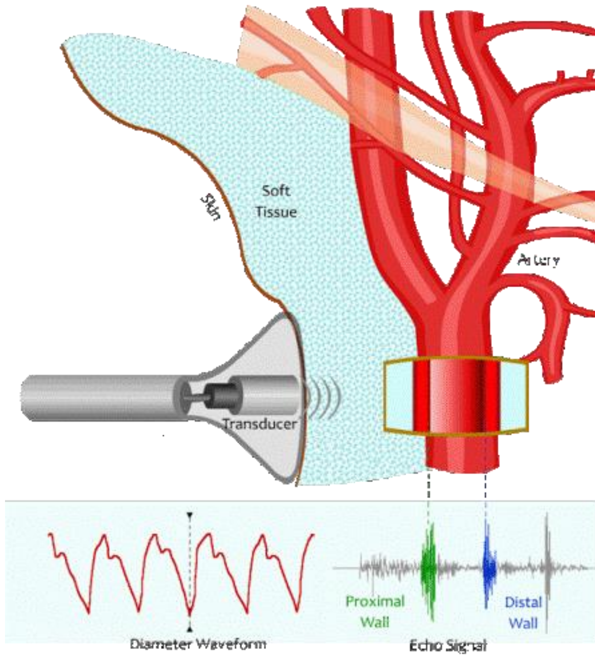

Figure 2. Principle of Image-Free Evaluation of Arterial Stiffness.

The carotid artery is chosen as the site of measurement. The single element transducer transmits the ultrasound into the body and also receives the reflected echoes. The arterial wall motions can be tracked to obtain a distension waveform and also measure the end-diastolic diameter. These can then be used along with blood pressure to calculate arterial stiffness estimates.

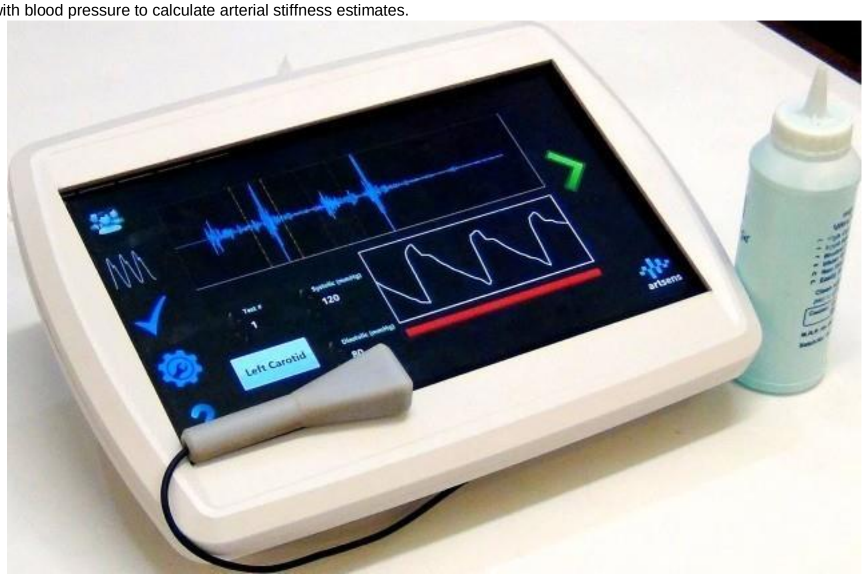

Figure 3a. Desktop Prototype of ARTSENS (tablet version)

Figure 3b. ARTSENS Measures Carotid Artery Stiffness of a Volunteer

HTIC developed miniaturised hardware modules for transducer excitation and synchronised data acquisition in-house and integrated them with intelligent computing modules for real-time processing and online signal analysis to develop a prototype device. HTIC is currently developing a handheld version of the ARTSENS device. Details of the technology development and use of NI systems in rapid prototyping and product development are provided in the project overview section.

Validation Results

ARTSENS technology was validated both a laboratory environment and clinical settings. Experiments with simulation platforms and artery phantoms demonstrated that ARTSENS could measure artery diameter and distension with error less than 10 percent and track wall motion with precision of 6 µm.

Preliminary validation studies in clinical settings have so far been performed at three clinical institutes on more than 600 subjects. An extensive field validation study of the technology is currently ongoing in Chennai and has completed more than 500 subjects to date.

Validation Study Phase 1—In Collaboration With Mediscan Systems, Chennai

This study compared the arterial stiffness measurements performed using ARTSENS with those taken using a state-of-art imaging system (Aloka Prosound α10 with eTracking) to evaluate the measurement accuracy of ARTSENS. In-vivo measurements were performed on 106 subjects in this study. The results from this study showed strong correlations between ARTSENS measurements and those taken using the imaging system. Linear regression correlation coefficient for arterial stiffness index, β and arterial compliance, AC measured from ARTSENS with respect to Aloka system was 0.7. Increased arterial stiffness with age was also observed, indicating the ability of ARTSENS to detect age-related changes in artery wall properties.

Figure 4. Validation Study of ARTSENS in Comparison With Imaging System at Mediscan Systems, Chennai

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Validation Study Phase 2—In Collaboration With Thambiran Heart and Vascular Care Institute, Chennai

This study was conducted following improvements made in the hardware and software of ARTSENS, to further validate the ability of the technology to accurately measure arterial stiffness in comparison with state of art imaging systems. In addition to arterial stiffness measurements, anthropometric data and biochemistry parameters were collected from 125 subjects. Strong correlations were observed between ARTSENS measurements and those made by the Aloka imaging system in this study. The linear regression correlation coefficient (r), for arterial stiffness index, β was 0.9, for arterial compliance, AC was 0.7 and for elastic modulus, Ep was 0.9. Increase in arterial stiffness with age was apparent in this study also.

Figure 5. Validation Study at Thambiran Heart and Vascular Care Institute, Chennai

Usability Study in Medical Camp Setting

To investigate the ability of ARTSENS to perform quick measurements in a screening scenario, the ARTSENS prototype was deployed in a vascular screening camp. ARTSENS was used to perform stiffness evaluation on more than 50 subjects within the four-hour period of the camp.

Figure 6. ARTSENS Used in a Vascular Screening Camp in Chennai

Validation Study Phase 3—Large Scale Clinical Study

An extensive clinical study of the ARTSENS device, to compare arterial stiffness estimates of ARTSENS with conventional measures and other cardiovascular risk factors, is currently underway at Sri Ramachandra University, Chennai. ARTSENS measurements were compared with pulse wave velocity, an established marker of vascular stiffness. Increasing arterial stiffness with age was indicated by increasing pulse wave velocity and stiffness readings of ARTSENS. Results from nearly 400 subjects indicate that ARTSENS can detect increased arterial stiffness associated with the presence of risk factors such as low HDL, diabetes, and more, demonstrating the strong potential of ARTSENS technology in screening and early detection.

Figure 7. Clinical Validation Study of ARTSENS at Sri Ramachandra University, Chennai

Validation Study Phase 4—Field Feasibility of ARTSENS

To evaluate the practical feasibility of performing arterial stiffness in actual field settings, a large scale study is currently underway in the rural outskirts of Chennai, in Gudapakkam. The study is conducted in collaboration with the National Institute of Epidemiology, an institute of the Indian Council of Medical Research and is targeted at establishing the field feasibility of ARTSENS, and also in creating a database of vascular stiffness and other risk factors relevant for the Indian population, for use in future screening studies. The first phase of this study has been completed over a period of six months on more than 640 subjects.

In this study, ARTSENS was taken to the field and operated in outdoor environments by nonclinical personnel. Results from the initial phase of this study demonstrated feasibility of performing arterial stiffness measurements, even in very resource-constrained settings. A few snapshots of ARTSENS being used in field settings is shown in Figure 8 and Figure 9.

Figure 8. Field Validation Study of ARTSENS

Figure 9. Using ARTSENS in the Field for Evaluation of Carotid Artery Stiffness

Technology Evolution of ARTSENS and Role of NI Systems, a Clinician's Challenge

ARTSENS was developed to address the need of an easy-to-use, nonexpert operable device to quickly and reliably measure carotid artery stiffness, with potential use in large-scale vascular screening. The genesis of this project happened in 2008, when Dr. Suresh, eminent ultrasound expert and Director of Mediscan Systems, Chennai threw out an open challenge to a few researchers at IIT Madras. Dr. Suresh, while being convinced of the benefits of using arterial stiffness for screening, was frustrated with the limitations of the technology at his disposal for measurement of arterial stiffness. The ultrasound machine that he used to measure stiffness required the subject to lie down, connect ECG leads, and then a trained sonologist had to capture an ultrasound image sequence of the artery. During the procedure, the operator also had to analyse the image on-screen and mark the locations of the artery walls for the machine to perform artery "wall-tracking." Then the operator had to go the post analysis screen and select the correct

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Figure 10. Image-Based Measurement of Carotid Artery Stiffness

The operator must identify the artery anatomy on the ultrasound image. Further, selection of correct cardiac cycles are also required to ensure reliable measurement. ECG gating is also used.

Realising that this method was not scalable for field deployment, he challenged IIT Madras to develop a simple, easy to use, automated technology that could provide him the same numerical estimate of stiffness, called beta stiffness index in clinical parlance, which could be affordable, portable and amenable for field deployment. The major challenges to be addressed by R&D in the development of this affordable vascular screening device were that the measurement should be:

Non-invasive

Automated as much as possible

Easy to perform

Reliable and repeatable

Also, the instrument should be:

Small

Portable

Intuitive to use

Early R&D and Origin of Image-Free Method for Stiffness Evaluation

Research at IITM started with the prime objective of removing the need of an expert sonologist to perform carotid artery stiffness evaluation. This meant development of an alternative sensing and measurement modality that did not need an image. The decision to develop an image-free sensing modality was crucial as it was essential to solve the biggest hurdle faced by state of art, that is, the need for an expensive equipment and expert operator to perform the test.

Since the measurement had to be performed noninvasively, it was decided to adopt an ultrasound-based sensing technique. This was inspired by the use of nonimaging ultrasound transducers for inspection of defects in metals. Early experiments to verify the possibility of using nonimaging ultrasound sensors to detect echoes from artery walls were conducted at the Non Destructive Testing (NDT) laboratory in IIT Madras. A Panametrics V110 RM, 5 MHz, single-element ultrasound transducer, designed for use in NDT, was used for early studies. An industrial pulser receiver was used for transducer excitation and signal amplification. The echoes were digitised using a PCI-5112 scope card and analysed using a LabVIEW (http://www.ni.com/labview/) VI running on the PC. The overall schematic is shown in Figure 11.

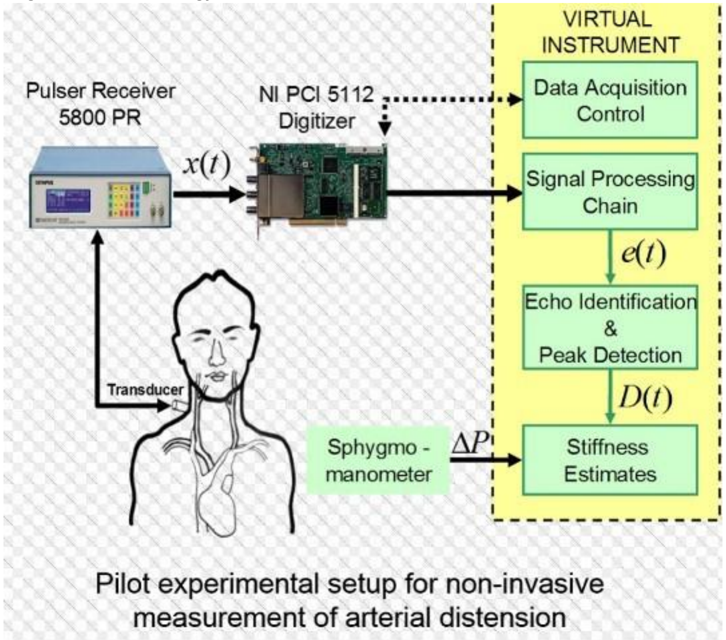

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Figure 11. Early Experimental Setup Using NI Hardware and the Front Panel of VI Developed for the Experiment.

The VI illustrates the echo signal received from the artery, and the diameter waveforms measured after manual identification of vessel walls. The use of NI hardware and LabVIEW software allowed quick experimental setup and allowed the research team to capture the echo signals and focus on understanding the signal characteristics, without getting bogged down with the setting up of the experiment.

This experiment demonstrated that the artery walls could be visualised on the echo signals captured using a single element transducer and established that an image-free modality was indeed feasible. However, the identification of the artery anatomy from the echo signal was extremely difficult and had to be performed manually.

Laboratory Prototype for Image-Free Evaluation of Artery Stiffness

Following the proof-of-concept experiment, it was very evident that the success of this R&D hinged on the creation of a robust and reliable signal processing and automated measurement algorithm. Development of such an intelligent algorithm required extensive signal analysis to understand the signal morphology. This required the creation of a database of signals which could only be attained by extensive experimentation.

Hence, a laboratory prototype, which allowed real-time signal capture and online signal analysis and data storage, was designed. The schematic of this laboratory prototype is illustrated in Figure 12. It was based around an NI PXI-6602 (http://sine.ni.com/nips/cds/view/p/lang/en/nid/1124) counter timer card used for high-frequency pulse generation that could drive the transducer excitation circuitry, operating in sync with an NI PXI-5152 (http://sine.ni.com/nips/cds/view/p/lang/en/nid/203069) scope card for signal acquisition. A dedicated VI was developed for pulse generation, synchronised data capture, real-time signal analysis, and results display and data storage. Following the development of the laboratory prototype, extensive experimentation was performed on simulated signals, artery phantoms, and volunteers.

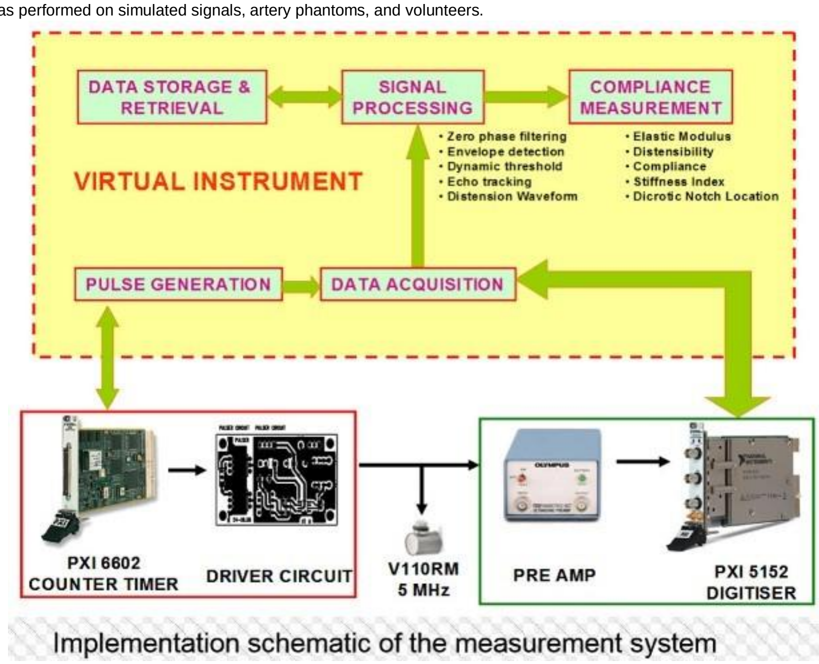

Figure 12. Schematic and Snapshot of the Laboratory Prototype Instrument for Image-Free Evaluation of Arterial Stiffness

The ability of the prototype instrument to capture and analyse data in real time, using NI hardware and algorithms developed with LabVIEW, allowed rapid, iterative development in signal processing algorithms.

Every incremental modification that was made on the processing and measurement algorithm could be tested on volunteers by performing actual measurements and using this prototype. Following extensive experimentation on volunteers to evaluate various types of expected signals and difficulties in real-time measurements, a set of automated algorithms that performed real time artery identification, wall tracking, diameter and distension measurement, and calculation of numerical estimates of arterial stiffness were developed.

Following successful tests in the laboratory, it was decided to take the project to the next step and perform measurements in clinical scenarios. Towards this, a much more portable desktop prototype was developed for use in clinical studies.

ARTSENS Desktop Prototype

The desktop prototype of ARTSENS, developed for use in clinical studies, and for measurement in settings outside laboratory environments, is illustrated in Figure 13. The system had a dedicated hardware unit, connected to a laptop through USB. A custom hardware board was developed for transducer excitation and analog signal processing, with onboard microcontroller and dedicated power stages for both low voltage and higher voltages needed for transducer excitation. The amplified echo signals were digitised using a NI USB-5133

Learn more about digitiser at 100 MS/s and sent to the laptop. The VI running on the laptop performed real-timeour privacy policy. (http://www.ni.com/legal/privacy/unitedstates/us/) signal analysis to identify arterial walls, track wall motion, and perform stiffness measurements. The instrument was thus a fully functional unit and could be used for performing measurements on volunteers. Moreover, in the absence of an image, the operator had no means to know whether the probe was positioned correctly, and whether the echo signals received by the probe were actually coming from the carotid artery itself. To overcome this limitation, an automated algorithm needed to be developed. O

However, unlike other bio-signals, with databases available from prior studies, there was no available database of typical echo signals received by reflection from the carotid artery.

Hence, the next step was creating dedicated laboratory equipment to capture and analyse signals in real time that would also allow the creation of a database of echo signals for development of automated measurement algorithms.

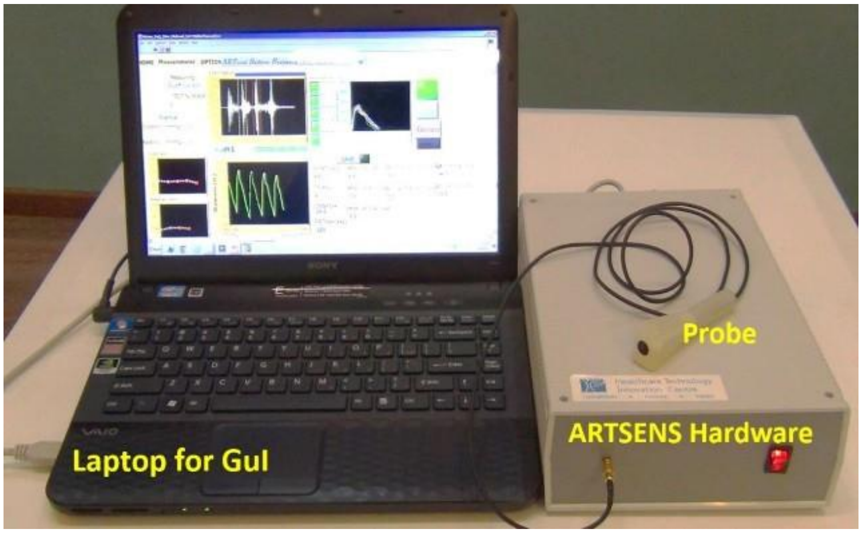

Figure 13. ARTSENS Desktop Prototype

Multiple units of this design were made and deployed in various clinical centres for validation studies. This instrument was validated in multiple clinical institutes such as MediScan, Thambiran Heart and Vascular Institute, and Sri Ramachandra University, Chennai, cumulatively on nearly 1,000 subjects.

ARTSENS Touch: A Portable Device for Carotid Artery Stiffness Evaluation

Following successful validation of the desktop version of ARTSENS, there was a strong requirement from the collaborating clinical institutes for the development of a smaller, portable instrument. Hence, a touch screen-based version of ARTSENS was developed. A rugged version was also developed to be used for field studies. This device has so far completed more than 640 measurements in field.

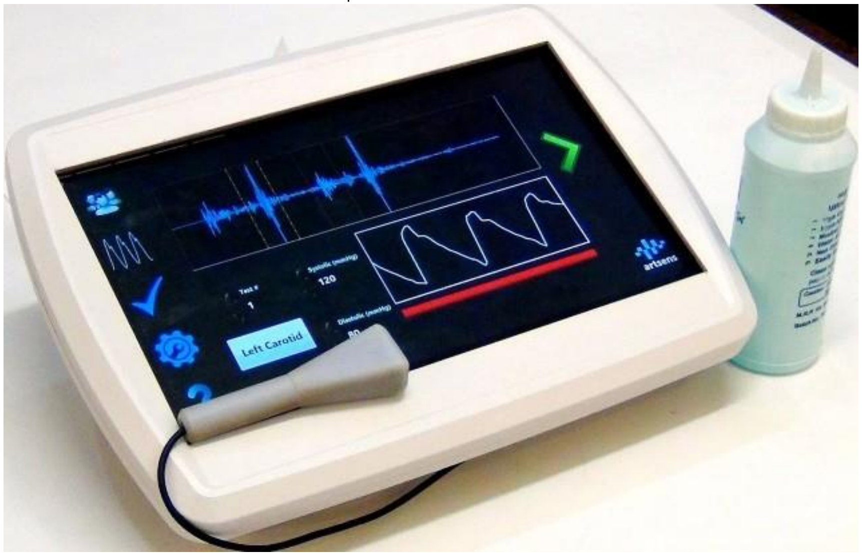

Figure 14a. ARTSENS Touch Prototype

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Figure 14b. Rugged Version Developed for Field Studies

In addition to changes in hardware, ARTSENS was continuously evolving its artery identification and automated measurement algorithms. Clinical studies generated enormous amounts of data that led to the evolution of advanced techniques for wall identification, rejection of incorrect anatomy, online evaluation of signal quality, segregation of high-quality measurements for improved reliability, and more. From the manual method that was adopted in the early laboratory prototype, the software evolved to perform the entire measurement with no operator input. Once the operator keeps the probe over the neck of the subject, the system could provide the stiffness readings within a minute. A very intuitive and easy to use graphical user interface was also added at this stage. A rugged version was also developed for use in field studies.

Seamless integration of NI hardware modules with software, a modular hardware and software interface, and signal processing modules in LabVIEW enabled a smooth and continued update of the intelligent measurement algorithms in various versions of ARTSENS. Translation of an algorithm developed by R&D to a deployable software module was extremely easy as the end product prototype could also be designed using the same software hardware architecture.

ARTSENS Mobile: From Development to Deployment

As can be seen from the evolution of ARTSENS presented above, the use of NI hardware and graphical system design tools helped us take up a very challenging R&D problem and develop a solution that worked in the clinical setting and in the field. The use of modular instruments and graphical system design tools enabled rapid development of functional prototypes that could be tested in both clinical and field settings. The project serves as a strong illustration to the amenability of NI hardware and software for rapid development of product concepts.

ARTSENS was conceived as a vascular screening tool, and the next step in its evolution was to develop a portable product design. However, the NI hardware modules used so far in the development could not be used at this stage, as this product required a very small embedded processor that could support all the measurement functionality needed in ARTSENS and offer a smooth user interaction as well.

Hence, HTIC developed a portable version of ARTSENS using a traditional embedded development platform. An OMAP L138 processor-based design was developed and the entire ARTSENS algorithm was ported to the processor. Significant time was spent on porting the algorithms and developing a user interface. As this was a traditional embedded design, it was not possible to leverage the extensive set of algorithms that were already developed with LabVIEW for deployment in the embedded product.

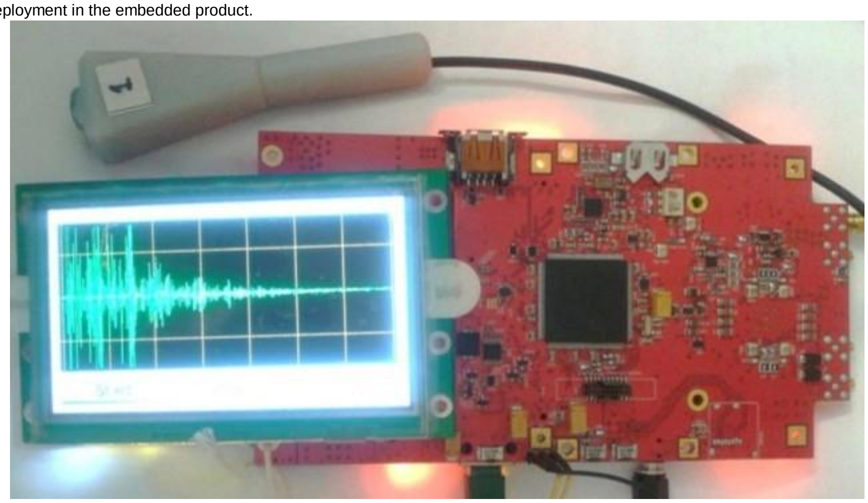

Figure 15. ARTSENS Mobile Developed Using Traditional Embedded Design Architecture

The release of the sbRIO-9651 System on Module (SOM) overcame this limitation and is currently powering the progress of ARTSENS to a portable, fiel d deployable device for quick and easy evaluation of arterial stiffness for vascular screening. ARTSENS Mobile is designed around the sbRIO-9651and can interact with a smart device such as a phone or a tablet that serves as the operator interface. Ongoing development, using the SOM evaluation boards has demonstrated that the SOM can fulfill the functional requirements of ARTSENS. The signal processing and automated measurement algorithms have been deployed onto the SOM and a functional prototype of the system concept has been developed. A custom board using SOM is under development.

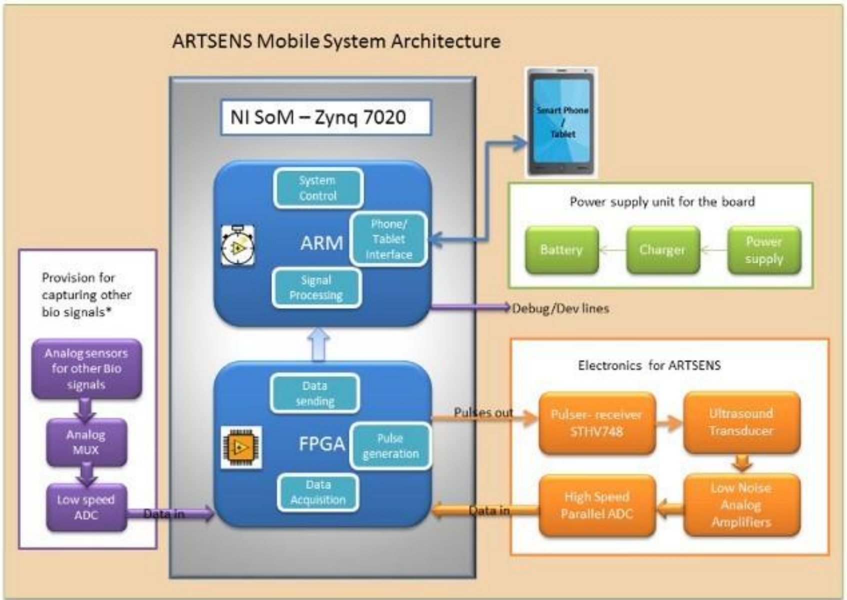

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Figure 16. System Architecture of ARTSENS Mobile Using SOM

Figure 17a. ARTSENS Board Interfaced With SOM

Figure 17b. Stiffness Measurements Performed In-Vivo Using ARTSENS Implemented With SOM

Summary of ARTSENS Technology Evolution

The ongoing development of ARTSENS Mobile using SOM is the latest chapter in a long R&D journey powered by NI tools all the way from proof of concept, prototype development, field experimentation, to final product development and deployment. The availability of SOM has now enabled us to take the project concept from prototype development to product design and deployment.

List of clinical collaborators

1. Mediscan Systems, Chennai
2. Thambiran Heart and Vascular Institute, Chennai
3. Sri Ramachandra University, Chennai4. National Institute of Epidemiology, Chennai

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