
Reporting

Project Information

COMP-HEALTH
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Coordinated by
E.T.S. SISTEMI INDUSTRIALI SRL
Italy


Executive Summary:
Application of composite materials for transport is increasing, mainly driven by the need to decrease mass, reduce manufacturing costs and increase performance in order to reduce direct operating costs (fuel consumption, maintenance etc.) for the operator. In terms of strength to weight ratio and stiffness to weight ratio, they outperform most metal alloys. For composite materials, Non-Destructive Testing (NDT) is particularly important because the material is manufactured simultaneously with the component, making it more probable that defects will be present in the finished item. Unfortunately, composites are also extremely sensitive to impact, making it more likely that critical size flaws will also be generated in service.
Besides the transport sector, application of composites to safety and infrastructure critical applications such as aerospace and renewable energy is also increasing; however the cost of inspection is about 30% of the total cost of acquiring and operating composite structures. This large proportion of the total cost makes the need for effective inspection critical not only to operational safety but also to the cost benefit of these materials. There is an urgent need to decrease the inspection cost, time and training required to interpret results in the case of composite materials. There are present inspection techniques for composite methods such as ultrasonic methods and shearography but they all have their limitations. Moreover, the total market size for NDT sector in Europe is approximately €900M. In the international arena, NDT products from Asia Pacific are thriving. This is true even for the more advanced techniques such as phased array ultrasonics (PAUT) and time of flight diffraction (TOFD), thermography and shearography. If Europe is to maintain a technological lead in NDT technology, then it is necessary to develop new techniques in parallel with the introduction of new materials. Hence, the comp-health project is conceived specifically to address these issues and to improve the competitiveness of the European NDT industry. This report describes the work undertaken and the results obtained throughout the entire duration of the Comp-Health project.

The Comp-Health system is a mobile scanner capable of detecting defects in composite materials and components, at both the point of manufacture and in-service/in-situ. The proposed project is based on the application of an electromagnetic sensor operating at Radio Frequencies (RF) at which the penetration depth is comparable with a typical thickness of a structural component (typically <10 mm) to detect critical defects much smaller than the wavelength. These defects constitute a serious risk to the performance of the composite materials and components. The probe utilizes an array of coupled spiral inductors with the circuitry printed on a flexible substrate in order to make measurements on plane or curve surfaces. The sensors array size is optimised taking account of both resolution and cost effectiveness. The array of sensors is mounted onto the mechatronics of the robot which aids in the precise positioning of the sensors to scan a composite surface of area >10 cm² within 5 seconds. It should also enable measurements on curved surfaces with radii of curvature ≥ 150 cm. All prototype software is executed on the MATLAB® platform which is also used to interface with the hardware. The complete RF system provides the user with a two-dimensional image showing the critical defects which may be present in the composite.

Project Context and Objectives:
Since the introduction of composite materials, predominantly Carbon Fibre Reinforced Polymer (CFRP), into a primary aircraft structures (i.e. rudder, engine strut fairing and elevators), there has been a renewed interest in portable testing devices for use during manufacturing and in-service/in-situ inspection. Owing to the advance manufacturing of CFRP, the fibres can be oriented to match the direction of principal stress which as a consequence increases the structural efficiency which outperforms most metal alloys. In addition, the flexibility in term of manufacturing complex shapes from low cost tooling and resistance to corrosion are some of the advantages for using CFRP. The great benefits of high specific strength and specific stiffness ratios for CFRP have led to its increased usage in many demanding applications notably in the aerospace industry. The use of CFRP material in aircraft results in a reduction in fuel consumption and reduction of carbon emission per passenger by ca. 20%, compared with traditional aircraft made using conventional materials operating at the same speed which makes them very attractive for the aerospace industry.
Although the anisotropic nature of composite materials means that strength and stiffness can be tailored accurately to bear the expected loads, this may result in a less damage tolerant structure at certain points or regions. Composites can develop safety critical defects and the nature of these defects is different from the defects encountered in metals. Little is known about service defects in structural composites compared with metal defects simply because the replacement of metals by composites is relatively recent and this being the case it is likely that there are new possible failure modes for composites in safety critical applications that are yet to be discovered. This possibility is indicated by the case of the American Airlines Flight 587 which broke apart over New York in 2001 (265 fatalities) due to the failure of the tail fin despite routine non-destructive testing (i.e. ultrasonic methods and shearography) and visual inspections. As a consequence, reliable inspection of structural composites for the identification of critical defects is crucial for the avoidance of future catastrophic structural failures which may endanger human life.

The aim of the Comp-Health project is to develop a “real-world”, mobile scanner which can be used to detect defects in composite materials and components, at both the point of manufacture and in-service/in-situ. In this project, we are attempting to circumvent the shortcomings of traditional inspection methods by adopting a novel Radio Frequency (RF) technique. The motivation in this project is to exploit the RF technologies to detect and characterise damages on CFRP (predominantly but not restricted to) which may not be visible on the surface. The proposed project is based on the application of an electromagnetic sensor operating at RF frequencies at which the penetration depth is comparable with a typical thickness of a structural component (typically <10 mm) and detects critical defects much smaller than the wavelength (>3 mm). The complete RF system will provide the user with a two-dimensional image showing the critical defects which may be present in the composite. The challenge in this project is how to offer a feasible solution based on RF technologies to increase the Probability of defect Detection (PoD) whilst keeping the virtues of low cost, fast scanning speed and portability. Benefits which will be gained from the Comp-Health project are manifold:

i) Improved confidence in inspection performance such as detection of delamination diameter that are 6 mm and above.
ii) Improved quality and safety assurance.
iii) Unlike ultrasonic testing, no couplants are required.
iv) Unlike Shearography, it is not necessary to apply mechanical loads to the structure, simplifying and reducing set-up time.
v) Signal to noise level higher than for ultrasonics and shearography.
vi) Good repeatability of results compared with ultrasonics
vii) It is possible to implement the probe as a two dimensional array which will enable higher scan rates and thus reduced overall inspection time.
viii) High spatial resolution (related to probe dimensions)
ix) The probe array can be made conformable to cope with curved surfaces
x) Reduced risk of human error.

xi) Reduced operating and maintenance costs.
xii) Open new NDT product market.

However, in order for this technique to be fully implemented in a ‘real-world’ setting, there are a number of technical barriers that need to be overcome:
i) Development of a single reliable RF probe suitable to test for surface and volumetric defects in CFRP.
ii) Extend the single RF probe into a two-dimensional array with an optimised number of probes and spacing between them.
iii) It is also necessary to develop a mobile scanner able to detect defects over a large range of component shapes and varying composite materials.
iv) Image processing algorithm for the system visualisation in order for the inspector to understand and interpret the ‘radio maps’.

At the time of writing, this concept is novel.

Project Results:
For the initial phase of Comp-Health, the overall specification of the Comp-Health project detailing industry requirement and the Comp-Health system was documented. For testing throughout the whole span of the project, a range of CFRP test specimens (with and without specified defects) were manufactured by ATARD who has extensive knowledge of the composite materials (i.e. structural, fatigue and technical know-how on the manufacturing process) which are applicable in the aerospace industry. The defects include cracks, delamination, holes, bubbles and foreign inclusions (i.e. brush fibres). In order to characterize the samples, they have been subjected to advanced imaging process and elementary analysis (performed by NTUA) to reveal both the microtexture of the composite material and composition information (i.e. fibre volume composition). The average conductivity of the CFRP specimen has been evaluated by means of a single-post dielectric resonator (SiPDR).

A benchmark model which consists of a coaxial line coupled to a layered media has been used to verify the modelling results obtained using Finite Element Method (FEM, using COMSOL® software, performed by UBRUN) and FDTD (QuickWave® software, performed by WUT). The results show good agreement between the S11 parameters for both computation models. An alternative validation of the FEM model was performed using an open ended coaxial line to calculate the S11 parameter which agreed with literature. Laboratory measurements have been performed for CFRP samples with a coaxial sensor (performed by WUT). It has been observed that the coaxial probe is not recommended for the measurement of conductive materials since an electric field is effectively shorted by the sample. However, the experiment shows that it is still applicable for surface defectoscopy. There has been significant research work on exploring a more suitable probe which could have a higher potential in fulfilling the project objectives. One promising probe type is the use of a coupled microstrip inductor whose performance was demonstrated by WUT (on the test samples mentioned above) in the laboratory during the 6-month project meeting in Poland. The sensor has been shown to be the alternative to eddy current techniques, which are the most common for electromagnetic inspection of conductive materials. Such a type of probe exhibits a strong magnetic coupling with weak electric field which seems to be a favourable solution. It can operate at much higher frequencies, where the thickness of the composite is comparable with a skin depth in carbon (i.e. in relation to field penetration rather than a structural entity such as ply thickness). Some experiments using the spiral coupled microstrip inductors have also been conducted on samples provided by ATARD, including sensitivity tests for various operating frequencies (10, 25, 50 and 100 MHz) on sample S2_5. According to the results, an operating frequency of 10 MHz offered the best image of a buried hole for this particular sample (i.e. high contrast). The resolution of the acquired image was 4 mm and it is worth noting...
that the image was built up by manually displacing the sensor on the sample during the experiment. Improvement of the results will be improved with use of an automatic scanner (to be developed during the project). Experiments have also been performed on sample S2_3 and S2_4 on bump and delamination respectively with different probe orientation (0°, 45° and 90°). It has been observed that coupling decreases when the probe is rotated by 45° with respect to carbon fibres. As can be seen, spiral coupled microstrip inductors show encouraging results in our application.

A total of 6 representative CFRP composite samples (defect free and defect) have been measured using both the proposed RF (performed by WUT) and conventional UT (performed by UBRUN) techniques. The defects include spread bubbles, specific bubbles, cracks, holes and delamination. Based on the laboratory results, the measurements based on RF technique are very promising since almost all of the defects are well detectable. In comparison with the immersion UT test, results show that the UT technique is capable of detecting certain defects, albeit with a low confidence level, but there are also several measurement examples where sensitivity is very poor. Another aspect of the study is to develop the algorithm for processing of such RF maps that will allow detection (deconvolving) of composite defects (performed by WUT). For the purpose of defect classification the classification-trees approach was used whereas for the purpose of spatial processing, an algorithm extracting the information about the defects in the form of binary images has been developed. The spatial processing was developed and tested on both simulated and real measurements. In addition, a visualisation tool, that allows a manual analysis of radio maps, has been developed. The results of classification of the simulated data confirm the usefulness of the proposed approach, showing the possibility to classify the measurements with regard to defect type (specific bubbles, spread bubbles, cracks, delamination and holes) and its depth position in the composite. The sensor array holder of the RF sensors has been designed, manufactured and tested (performed by NTUA). Two active and three passive degrees of freedom have been incorporated in the system, enabling it to provide the proper motion and conformance during the inspection. The functionality and movement accuracy (< 0.5 mm) of the sensor holder positioning are achieved. RF array inductors were also designed (simplicity and scalability), manufactured and tested of both rigid and flexible substrate successfully (performed by WUT). A dedicated multi-channels measurement system based on well-known device (called a wobullator) is designed, manufactured and tested. The data acquisition system is capable of operating from 1 to 400 MHz (sufficient for our purpose based on theoretical and experimental test) and is powered up by +5 VDC. The measurement circuit is controlled by a fast 32-bit ARM-based microcontroller, STM32F303RCT6, which serves as an interface between electronics described above and a PC-host.

Using the sensor array developed in WP3 (D 3.1). Along with the hardware equipment produced on this phase, the proper algorithms (matlab based) for scanner manipulation and control were also implemented. The overall size of the scanner chassis frame is 600x400x250 mm and weight about (ca. 14 kg). The power source is mounted within the chassis boundaries and provides the scanner with voltage supply options of 5-12-24V DC. Some safety features are also implemented in the system (i.e. limit switch and protection pad). The system is able to perform X-Y scanning over an area with dimensions 300 x 200 mm after mounting the scanner over the composite surface. Plastic suction cups were implemented in order to aid stability for the scanner hardware over the inspected area. The integration of hardware and software (including testing and optimising) for the Comp-Health system were performed for WP5 (done by WUT, NTUA, UBRUN, ETS, ATARD). Some modifications to the Comp-Heath prototype system have been
performed during the integration phase such as adding a large air reservoir in the pneumatic vacuum suction system to enhance the suction ability. There was also some troubleshooting of electronics component which malfunction (i.e. Data acquisition system amplifier). The pre-operational test and operation procedures for the system were documented. The scanner position feedback accuracy is also tested with long and short scanning distances (both $x$ and $y$ axes). The results yields very good position accuracy ($<0.5$ mm). With the successful integration of the scanning system as validated in WP5 and the addition of several minor modifications, further inspections on various composites geometries (plane and curve) and different types of defects (holes, cracks, delamination, bubbles) were carried out for further analysis in order to fully assess the performance of the current system. The current results for inspection on planar and curved CFRPs has demonstrated the functionality and operations of the fully integrated system prototype as well as its ability to detect crack, hole, delamination, specific bubble and spread bubble defects of various size and depth location. The stability of the system using the simultaneous vacuum suction procedure during measurement was also demonstrated with success on the planar sample. The Comp-Health project has taken the exploitable results to minimum Technology Readiness Level (TRL) 4. Up to TRL6 the Technology Push of a research and development takes place and later on, i.e. beyond TRL6, it is replaced by the Market Pull of production engineering to meet specific commercial demands.

The Plan for use and Dissemination of the Foreground (PUDF) was drafted and produced (see D7.3) within the entire period of the project. The PUDF includes the potential to attract investment for the Comp-Health technology beyond the duration of the project. Concerns and questions have been raised by partners with regards to the protection of IP and have been answered during partners meetings and through email exchanges. The consortium is interested in patenting either the entire concept of the Comp-Health system or individual components of the technology which will be reported in the final PUDF.

The website for Comp-Health is accessible on the public domain using the following URL:

http://www.comphealth.eu

Information in the website is up-to-date.

The project flyer has been designed and disseminated to external parties to create awareness for this project (see D7.4).

Based on the outputs of the research and development work so far, there have been eight scientific publications submitted to 2 peer reviewed journal and 6 international conferences as follows:


iii) P. Korpas, B. Salski and S. Reszewicz, “Multichannel measurement system for non-destructive testing of carbon-fiber-reinforced polymer composites”, IEEE Transactions on Microwave, Radar, and Wireless Communication (MIKON), Gdansk, Poland, 2013. DOI: 10.1109/MIKON.2014.6899841
Work Progress

WP1
Overall specification of the Comp-Health project detailing industry requirement and the Comp-Health system have been documented. The complete RF system will provide the operator with a two-dimensional image showing the critical defects which may be present in the composite. The challenge in this project is how to offer a feasible solution based on RF technologies to increase the Probability of defect Detection (PoD) whilst keeping the virtues of low cost, low power consumption and portability. During the Kick-off meeting, consensus was reached for all partners that the project should start with investigation of a simple case (i.e. single layer of only the composite (carbon fibre + resin) with fibre volume fraction of about 60% (typical for aerospace application) and uniform fibre orientation (multi-axial is used for structural body parts). Once knowledge has been built up, more complicated configurations will be studied. Also information of the damaged samples (i.e. types of defects, size and location) should be known to allow more control in the studies. Real (unclassified) defects can be attempted at a later stage.

A range of CFRP test specimens (with and without specified defects) has been manufactured, which subsequently will be used throughout the duration of the project. These samples were provided by ATARD who has extensive knowledge of composite materials (i.e. structural, fatigue and technical know-how on the manufacturing process) which are applicable in the aerospace industry. A total of 10 test samples consisting of single layer (x 04) and multi-layer (x 06) CFRP with and without defects have been described in D1.1 section 3. The defects include cracks, delamination, holes, bubbles and foreign inclusions (i.e. brush). Carbon fibre with twill design was used for the reinforced material and epoxy resin was used as the matrix material. The prepregs were orientated unidirectionally for the multi-layer composite. In addition a polyester gel coat was used as coating material on one side of the surface. Both manufacturing processes known as vacuum infusion and hand lay-up process have been used to produce different types of defects
In order to characterize the samples, they have been subjected to advanced imaging and elementary analysis (performed by NTUA) to reveal both the microtexture of the composite material and composition information (i.e. fibre volume composition). The average conductivity of the CFRP specimen has been evaluated by means of a single-post dielectric resonator (SiPDR) performed by WUT. A benchmark model which consists of a coaxial line coupled to a layered media has been used to verify the modelling results obtained using Finite Element Method (FEM, using COMSOL® software performed by UBRUN) and FDTD (QuickWave® software, performed by WUT). The results show good agreement between the S11 parameters for both computation models. An alternative validation for the FEM model was performed using an open ended coaxial line to calculate the S11 parameter which agreed with literature. Methods must be found to enable penetration of waves through the entire thickness of the material and generate a measurable signal from such non-isotropic material in order to have a tangible advance in the performance of the RF technique.

There has been significant research work on exploring a more suitable probe which could have a higher potential for fulfilling the project objectives. One promising probe type is the use of a coupled microstrip inductor where the performance was demonstrated (on the test samples mentioned above) in the laboratory during the 6-month project meeting in Poland. The efficient performance of the integrated probes array system on surface with curvature and a scanning hardware for providing the automation to perform the inspection have been discussed. The successful implementation of the probe array depends largely on the understanding the radiating/scattering problem of a single probe array.

WP2

The objective in WP2 is to develop a detailed understanding of the effect of defects in composite materials (i.e. fibre fracture, de-lamination, voids and wrinkles) on the detected RF-mapping image, including multiple defects and develop a specification to identify significant defects. In addition, an image processing methodology has to be developed which permits unambiguous interpretation of the RF maps in terms of damaged area dimensions and character.

Laboratory measurements have been performed for CFRP samples with a coaxial sensor performed by WUT. It has been observed that the coaxial probe is not recommended for the measurement of conductive materials since an electric field is effectively shorted by the sample. However, the experiment shows that it is still applicable for surface defectoscopy.

A new type of an electromagnetic sensor (spiral coupled microstrip inductors) for non-destructive testing of carbon-fiber reinforced-polymer composites has been investigated by WUT. The sensor has been shown to be the alternative to eddy current techniques, which are the most common in electromagnetic inspection of conductive materials. Such a probe exhibits a strong magnetic coupling with a weak electric field which seems to be a favourable solution. It can operate at much higher frequencies, where the thickness of the composite is comparable with a skin depth in carbon. Some experiments using the spiral coupled microstrip inductors have also been conducted on samples provided by ATARD, including sensitivity tests for various operating frequencies (10, 25, 50 and 100 MHz) on sample S2_5. According to the results, an operating frequency of 10 MHz offers the best image of a buried hole for this particular sample.
The resolution of the acquired image is 4 mm and it is worth noting that the image was built up by manually displacing the sensor on the sample during the experiment. Improvement of the results will be achieved with use of an automatic scanner (to be developed during the project). Experiments have also been performed on sample S2_3 and S2_4 on bump and delamination respectively with different probe orientation (0°, 45° and 90°). It has been observed that coupling decreases when the probe is rotated by 45° with respect to carbon fibers. As can be seen, spiral coupled microstrip inductors show encouraging results in our application. In addition, due to the processing technology on a PCB substrate applied, the method is easily extendable to an array in order to increase the throughput of a measurement cycle. Moreover, if a flexible substrate, like PTFE, is used, measurements of curved geometries could be performed in situ without any special efforts, which is the main challenge for other known NDT techniques.

A total of 6 representative CFRP composite samples (defect free and defect) have been measured using both the proposed RF (performed by WUT) and conventional UT (performed by UBRUN) techniques. The defects include spread bubbles, specific bubbles, cracks, holes and delamination. Based on the laboratory results, the measurements based on RF technique are very promising since almost all of the defects are well detectable. Taking account of the anisotropy of the material properties in the CFRP samples, the RF measurement clearly demonstrates the detection on the orientation of the prospective internal failure. The results have shown that the rotation of the RF probe could substantially enhance the accuracy of the measurement. In comparison with the immersion UT test, results show that the UT technique is capable of detecting certain defects, albeit with a low confidence level, but there are several measurement examples where sensitivity is very poor. Such results are quite expected in composite as the method is known to be noisy due to the scattering effect.

Another aspect of the study is to develop the algorithm of processing of such RF maps that will allow detecting (deconvolving) composite defects (performed by WUT). It will produce a binary image of the same size and resolution as the radio map, indicating the position and shape of the defects (i.e. value 0 for a non-defect point and 1 for a defect). For the purpose of defect classification the classification-trees approach was used. The spectral data being the result of simulations were converted into two sets: a learning set and an evaluation set. Each sample belonging to these sets was labelled by the identifier of the defect. Sets were used to produce the classification tree that consists of consecutive tests on amplitudes on chosen frequencies. For purpose of spatial processing, an algorithm extracting the information about the defects in the form of binary images has been developed. This algorithm makes use of image processing spatial filters that allow removing the noise and detecting the position of a defect. The spatial processing was developed and tested on both simulated and real measurements. In addition, a visualisation tool, that allows a manual analysis of radio maps, has been developed. The results of classification of the simulated data confirm the usefulness of the proposed approach. Probing of a composite yields good quality data and with the ground-truth data available for a composite, it would be possible to classify the measurements with regard to defect type (specific bubbles, spread bubbles, cracks, delamination and holes) and its depth position in the composite.

WP3

The objective in WP3 is to design a handheld electronic module measuring transmission through the set of RF channels connected to the one-dimensional and, later, two-dimensional sensor array.
The module has been designed, developed, experimentally tested, and initial measurements have been undertaken. The results show that additional calibration has to be undertaken for all RF channels individually due to the observed systematic variation of RF detectors. Simultaneously, 1D and 2D sensor arrays have been manufactured and tested together with the electronic module (performed by WUT). The results show that buried defects are detectable and the performance of the system can be improved even further if the already mentioned calibration is applied. Additionally, the concepts for the development of the mechanical arms for the linear and planar-conformable sensors respectively have been designed (performed by NTUA) and will be implemented on the second period of the project.

The sensor array holder of the RF sensors has been designed, manufactured and tested (performed by NTUA). Two active and three passive degrees of freedom have been incorporated in the system, enabling it to provide the proper motion and conformance during the inspection. The proper selection of the material used for the holder ensures the part close to the RF sensors does not interfere with the electromagnetic (EM) waves produced by the sensor. Magnetic encoders are implemented to indicate the position of the RF sensor array during the measurement and will be used in the main Comp-Health system software for the scanner control and data acquisition. The vertical Z-axis force towards the CFRP surface is provided by a “scissor-like” mechanism that drives a passive spring on the outside of a telescopic pair. The exerted force over the sensor plate can be adjusted via the use of springs with different mechanical properties in order to maintain firm contact with the inspected surface, during the sliding movement of the sensors. The functionality and movement accuracy (< 0.5 mm) of the sensor holder positioning are achieved via the use of high precision engineering components such as the rotating shafts, the bearings on all shaft ends, the magnetic encoders, the pivoting bracket and the scissors mechanism. Protection pad is also implemented in the development of conformable area array to avoid damage on the sensor and test surface.

RF array inductors were designed (simplicity and scalability), manufactured and tested of both rigid and flexible substrate successfully (performed by WUT). In the system, miniature U.FL coaxial connectors have been applied to reduce the total area of the array. A dedicated multi-channels measurement system based on well-known device (called a wobullator) is designed, manufactured and tested. The data acquisition system is capable of operating from 1 to 400 MHz (sufficient for our purpose based on theoretical and experimental test) and is powered up by +5 VDC. The measurement circuit is controlled by a fast 32-bit ARM-based microcontroller, STM32F303RCT6, which serves as an interface between electronics described above and a PC-host.

Test result shows that accurate measurements and the effective applicable on both planar and curved surfaces of radius >1500mm is achievable.

WP4
The main objective of WP4 is the development of a portable, handheld and automated scanning system (performed by NTUA) for carbon reinforced composites inspection. System’s operation regards the CFRP testing on both manufacturing and in service stages, using the sensor array developed in WP3 (D 3.1). Along with the hardware equipment produced on this phase, the proper algorithms (matlab based) for scanner manipulation and control were also implemented. The development of a lightweight construction was of prime importance, due to the need of manual handling and so light structural materials were used for the development of the aforesaid device. The overall size of the chassis frame is 600x400x250 mm.
Additionally; scanner design precautions were taken into account preventing in such a manner any potential electrical noise interference with the RF sensors. The power source is mounted within the chassis boundaries and provides the scanner with voltage supply options of 5-12-24V DC. In order to ensure that the XY travel distances are kept within safe limits, each linear sliding stage has a couple of magnetic limit switches and once the limit is exceeded by the carriages, it will halt the operation to prevent damaging the equipment. The basic function of the integrated measuring equipment is to inspect planar and curved surfaces with rates higher than 10cm² within 5 seconds which is achievable through the use sensors array scanning at increased step.

The system is able to perform X-Y scanning over an area with dimensions 300 x 200 mm after attaching the scanner over the composite surface. Plastic suction cups were implemented in order to aid stability for the scanner hardware over the inspected area.

A central microcontroller is utilized for the following functions:

i) Attach-Detach of the scanner over the composite surface via the control of a suction pump.
ii) Central control of motorised X-Y movement and getting position feedback of the sensor head with the aid of the passive degrees of freedom.
iii) Full control of sensory modalities to achieve homing of the scanner, positioning on demand, scanning on demand etc...
iv) Interfacing with a PC control software and libraries (a USB to RS485 communication bridge between the scanner and the PC was designed and manufactured specifically for this robotic scanner).

WP5

The integration of hardware and software (including testing and optimising) for the Comp-Health system were performed for WP5 (done by WUT, NTUA, UBRUN, ETS, ATARD). The integration work mainly spans from the relevant activities such as sensor array design, sensor data acquisition development and scanner system development which are described in WP2 to WP4. Joint efforts of the Consortium have taken place on two planned occasions to perform the integration at UBRUN’s facilities on the following dates:

First system integration and testing activity: 19th May 2014
Second system integration and testing activity: 17th – 19th Sept 2014

Some modifications to the Comp-Heath prototype system have been performed during the integration phase such as adding a large air reservoir in the pneumatic vacuum suction system to enhance the suction ability. During these periods, there was a malfunction amplifier which needs to be replaced in the sensor data acquisition system. This is inevitable as low-cost electronics were used and large spike may occur during switching. Best practices for powering up and down the system are advised in order to prevent the problem from re-occurring. Also pre-operational test procedure for the system is written to make sure that the whole system is functioning well before taking any measurements. The scanner position feedback accuracy is also tested with long and short scanning distances (both x and y axes). The results yields very good position accuracy (<0.5 mm). Some initial testing were carried out with this integrated system prototype on both plane and curve CFRP samples (with and without defects). These larger and more complex (curve) CRFP samples were manufactured and supplied by ATARD in kind. The preliminary measurement clearly detected the hole (planar) and crack (curve) defects. During these tests, it is observed that the vacuum suction cup would need further enhancement in order to effectively conform to
the curve surface. However, such drawback does not impair the system to be fully tested to validate the proposed RF array technique.

WP6
The main objective of WP6 is to evaluate the suitability and performance of the fully integrated Comp-Health system prototype. With the successful integration of the scanning system as validated WP5 and the addition of several minor modifications, further inspections on various composites geometries (plane and curve) and different types of defects (holes, cracks, delamination, bubbles) were carried out for further analysis in order to fully assess the performance of the current system. The current results for inspection on planar and curved CFRPs has demonstrated the functionality and operations of the fully integrated system prototype as well as its ability to detect crack, hole, delamination, specific bubble and spread bubble defects of various size and depth location. The resolution achieved for these results for both x and y axes is 2 mm which is defined by the scanner step size. If need be this resolution can go higher however this will inevitably lengthen the scanning time. Nevertheless, the array of RF sensors provides an avenue to speed up the scanning operation with the current multi-channels data acquisition electronics for the sensor. The stability of the system using the simultaneous vacuum suction procedure during measurement was also demonstrated with success on the planar sample. The ease of mobility due to the current size and weight of the overall system (ca. 15 kg) has proven to be manageable by a single operator. Although the current system prototype has proven the concept, however, there are further improvements which could bring the prototype to achieve a higher technology level. Some of the possible improvements are:

i) Mounting the data acquisition system circuit board to the scanner (with proper routing of the cable).

ii) Proper packaging of the system for environmental harm protection.

iii) Re-routing of the power adapter to be an auxiliary component to aid the system certification process (i.e. system classify as low voltage equipment).

iv) The vacuum suction system and possibly the method of attachment will be an area of improvement (i.e. more flexibility for suction cups and support legs height adjustment).

The representative smaller scale CFRP test samples of similar composition and defects were subjected to ultrasonic test measurement for comparison with the RF techniques. In comparison with the immersion UT, results show that the UT technique is capable of detecting similar defects (hole, crack and delamination), albeit with a lower confidence level.

The Comp-Health project has taken the exploitable results to minimum Technology Readiness Level (TRL) 4. Up to TRL6 the Technology Push of a research and development takes place and later on, i.e. beyond TRL6, it is replaced by the Market Pull of production engineering to meet specific commercial demands.

WP7
A draft Plan for use and Dissemination of the Foreground (PUDF) has been produced by the Dissemination Manager (see D7.2). The PUDF includes the potential to attract investment for the Comp-Health technology beyond the duration of the project. The Comp-Health project has identified Exploitation and Dissemination Manager, Cem Sempaz of ATARD, who will assume responsibility for coordination of the project knowledge management and exploitation, with the full support of the Project Steering Committee (PSC).
Concerns and questions have been raised by partners with regards to the protection of IP and these have been answered during partner meetings and through email exchanges. The consortium is interested in patenting either the entire concept of the Comp-Health system or individual components of the technology which will be reported in the final PUDF. The website for Comp-Health is accessible on the public domain using the following URL:

http://www.comphealth.eu

It is used as a medium to disseminate knowledge and news bulletin for those interested in the technology. There is also a secure area where partners are able to exchange materials of confidential nature. This website will be updated during the progress of the project and beyond.

A project flyer has also been designed and hard copies (x 100) of the flyer have been distributed to each partner in order to disseminate them to external parties to create awareness for this project.

Consensus was achieved during the project Kick-Off meeting that the common practice of signing a Non-Disclosure Agreement (NDA) must be done when engaging external parties (such as manufacturing of the probe).

A final Plan for use and Dissemination of the Foreground (PUDF) has been produced by the Dissemination Manager (see D7.3) during the second half of the project. The PUDF includes the potential to attract investment for the Comp-Health technology beyond the duration of the project. Concerns and questions have been raised by partners with regards to the protection of IP and these have been answered during partner meetings and through email exchanges. The consortium is interested in patenting either the entire concept of the Comp-Health system or individual components of the technology which will be reported in the final PUDF. With such promising results on the current scanner system prototype, further inputs and comments from all other participating partners would facilitate into perfecting and fine tuning the scanner system for actual industrial use. In addition, identification of other applications which employs the use of CFRP can also be exploited.

The website for Comp-Health is up-to-date

Project flyer has been disseminated to external parties to create awareness for this project (see D7.4).

There are 5 international conference presented and 2 peer-reviewed journal. 1 conference abstract has also been accepted by the conference committee.

Plans have been made by Coordinator (ETS) to showcase the system prototype at Ferrari Fab in Maranello, Italy during April 2015. The workshop is entitled (in English): The Non Destructive Test in Automotive and Mechanics.

WP8

The liaison with the European Commission has been carried out in an appropriate manner via the coordinator of the Comp-Health project. Considering the loss of time in the beginning of the project since the project starts in December where the holiday seasons began. Inevitably the due deliverables were not submitted in a timely manner, nevertheless, the work produced were of good quality as demonstrated by the quality of the deliverables.
producing of 2 publications in this first reporting period. All participating SMEs (ETS Sistemi, KCC, Nemetschek, ATARD & Elmika) have been very active during the project and contributed on technical level, providing guidance to the RTDs, as well as on dissemination and exploitation issues.

Potential Impact:
The European Aviation Safety Agency has reported that 15% of fatalities are attributed to aircraft engineering failure in the period between 1997 and 2009. By effecting a step change in the probability of defect detection using the proposed automated RF technique, the Comp-Health project has the potential to provide a tangible contribution to aviation safety. It is anticipated that the Comp-Health system will provide increased reliability in detecting defects in CFRP. This inspection system will not only be applied in the aerospace sector but can also be extended to other safety critical industries such as renewable energy (i.e. wind turbine), automotive and marine (i.e. boat). We are also seeing technology transfer for civil engineering structures such as bridges that incorporate composites. This is viewed as an attractive market opportunity and a long term objective. In the short term, the market pull in the aerospace sector is significant where the need is to develop more reliable NDT techniques for aircraft structures. This represents a business growth opportunity for the Comp-Health SMEs and improves their competitiveness as it is estimated that worldwide air traffic will treble in the next 20 years. As a consequence, the aircraft fleet will double in the same period which would require more maintenance, repair and overhaul (MRO).

List of Websites:
http://www.comphealth.eu

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