## CS-ICT Project Report II

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<th><strong>Project</strong></th>
<th>New ICT Compressive sensing based trends applied to: multimedia, biomedicine and communications (CS-ICT)</th>
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<tr>
<td><strong>Project Leader</strong></td>
<td>Prof. Dr Srdjan Stanković</td>
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<td>Faculty of Electrical Engineering, University of Montenegro</td>
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<td><strong>Funded by</strong></td>
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Publishable Executive summary

This section should be of suitable quality to enable direct publication by the Ministry of Science in Montenegro. Please ensure that it is set out and formatted so that it can be printed as a stand-alone paper document not exceeding 1 page.

In addition, provide this section in Montenegrin language as a separate document.

Please include a summary description of the project objectives, a description of the work performed since the beginning of the project, a description of the main results achieved so far, the expected final results and their potential impact and use (including the socio-economic impact and the wider societal implications of the project so far). You should update this publishable summary at the end of each reporting period.

The aim of this project is to develop new algorithms and techniques for compressive sampling/sensing (CS) and spectral analysis of signals. Also, with the help of all partners involved in the project implementation, the aim is to design an interesting applications in order to become the most attractive and competitive laboratory for considered research field. On the basis of achieved results, the aim is to produce a hardware based solution (using programmable logical devices) which will perform the functions of the developed algorithms. In the cooperation with the partners, we will be working on the development and implementation of new techniques primarily for the applications in multimedia systems, biomedicine and communications. The important aspect of the project is staff mobility. Exchange of researchers provide getting a deeper and better insight into current achievements and state of the art in the research activities performed within each of the partner institutions. The mobility program should result in knowledge transfer and improvement of research and practical skills for project participants.

Since the beginning of the project, the following activities have been done:

1. CS reconstruction method for polynomial phase signals is proposed, based on Polynomial Fourier transform. These signals are important as they usually appear in communications and as such could be corrupted by other signals and disturbances, which make the analysis difficult if not impossible. As polynomial phase signals are not sparse in commonly used transform domains, standard CS algorithms applied in these transformation domains cannot provide satisfactory results. Therefore, sparsifying signal can be done by using the Polynomial Fourier transform. The proposed approach is generalized using time-frequency representations obtained by the Local Polynomial Fourier transform (LPFT). The results show remarkably successful signal reconstruction even in the case when less than 10% of samples are available. The results are presented in the form of scientific journal paper which is still under revision. The application of the results opens a great perspective for the improvements in communications, dealing with linear frequency modulated signals. The paper has been submitted to the IEEE Transactions on Signal Processing.

2. The gradient based algorithm for sparse signal reconstruction has been proposed. The proposed algorithm is based on minimization of the measure of signal sparsity. It uses the steepest descent method. The measure of signal sparsity is minimized by varying missing signal samples using the variable (decreasing) step size in iterations. The results are
3. Further results in the area of sparse signals reconstruction based on gradient method for the applications to 1D and 2D data are collected and presented in the form of journal paper. An adaptive procedure/algorithm is defined, which aims in recovering the missing samples/measurements from different types of signal sand images, which does not have to be strictly sparse. The algorithm shows an improved computational efficiency compared to commonly used existing methods and also it does not require the signal to be strictly sparse as the other algorithms do. The paper is submitted to journal Signal Processing Elsevier.

4. The efficient modification of gradient algorithm for image reconstruction has been done using the Discrete cosine transform instead of commonly used Discrete Fourier domain. The remarkable results are achieved showing the ability to reconstruct the natural images with even less than 50% of available pixels. This is important results due to the fact that most of the existing algorithms have many difficulties when dealing with the reconstruction of natural images. The results are presented at the conference Telfor 2014.

5. The theoretical and experimental analysis of signals that are sparse in the domain of Hermite transform is also finished in this period, as well as and the possibility of applying the CS approach to Hermite sparse signals. Special attention is dedicated to the relation between the number of missing samples in the signal and statistics of the noise (external noise or noise caused by missing signal coefficients). The results are collected and conference paper preparation is in the process.

6. Further results in the Hermite transform domain are formulated as a new algorithm for Compressive Sensing reconstruction. The Compressive Sensing problem is formulated in the Hermite framework, allowing fast and efficient reconstruction of missing data by exploiting the concentration of signal's representation in the Hermite basis. The Hermite functions have been used as a suitable basis for representation and compression of QRS complexes of ECG signals, important for diagnosis and medical treatment. It is shown that the reconstruction of ECG signals can be done using a few Hermite coefficients. The result are collected and written in the scientific paper form, which is submitted to the Electronic Letters journal. The paper is currently under review.

7. Also, a new signal demodulation procedure is proposed, that uses the CS reconstruction algorithms. When the signal parameters are matched, the algorithm returns single component, otherwise the algorithm returns zero value. After detecting all signal parameters, the signal amplitudes reconstruction is performed based on l1-norm reconstruction problem. The results are presented in the form of journal paper that is submitted for review in IEEE Transactions for Signal Processing and initial research has been presented on ELMAR 2014 conference.

8. The principal concept of polynomial phase signal reconstruction is extended to the signal with sinusoidal modulations that appear in radar communications as a result of micro-Doppler (the signals returned from the fast rotating parts of the moving target, which is used in radars for target identification). The results are presented at the TELFOR 2014 conference.
9. Compressive Sensing and image watermarking has been a topic of research in this period as well. The watermark embedding into the available measurements is tested, as well as the idea of using the Compressive Sensing as a watermarking attack. Most of the research efforts were focused on the analysis of effects on watermark detection caused by the CS reconstruction, where it has been shown that the watermark detectability strongly depends on the number of measurements used for reconstruction. The results are presented at the TELFOR 2014 conference.

10. The next topic is related to the development of hardware for digital image processing and filtering. The hardware is based on the analogue-digital design and it is aimed at removing high image degradations caused by impulsive noises that may appear during the transmission process. The conference paper, with the hardware realization, schemes and hardware performance, is in the preparation phase.

11. Analysis of wireless signals in digital communications and possibilities to apply the Compressive Sensing to the wireless signal reconstruction is examined. Filtering the interferences and unwanted components from the multicomponent signals in communications is performed. The method for separation of the Frequency Hopping Spread Spectrum and IEEE 802.11b wireless signals is proposed. The interference of these two types of signals is common problem in wireless communications. The proposed method does not require component by component classification and works well even in the case of overlapping components. The results are presented at the TELFOR 2014 conference.

12. The combination of the Compressive Sensing approach and time-frequency distributions is applied, in order to provide highly concentrated signal energy in the time-frequency domain. The main focuses in this research were: Finding suitable distribution for signal representation and providing sparse time-frequency representation of the signal. The results are published in the IET Radar, Sonar & Navigation Journal.

13. Special efforts have been made to extend the research to Compressive Sensing application in ultrasonic tomography for fluids velocity imaging. The proposed Zernike ultrasonic tomography method actually transforms the set of ultrasonic measurements ("time-of-flight" of the sound signal) to the expansion of the orthogonal Zernike polynomials. The critical part is the estimation of the coefficients in the polynomial expansions, given the ill-posseness of the problem. The new idea is to rely on random sampling of the space dependent signals (random measurements) and estimate these expansion coefficients by means of Compressive Sensing algorithm. Particularly interesting epilogue of the this research project could be to propose a rotating measuring system, performing acquisition at the random time intervals and therefore providing different ultrasonic "time-of-flight" measurement. The results are presented in the paper N. Besic, G. Vasile, A. Anghel, T.I. Petrut, C. Ioana, S. Stanković, A. Girard, G. d’Urso, "Zernike ultrasonic tomography for fluids velocity imaging based on pipeline intrusive time-of-flight measurements", IEEE Transactions on Ultrasonics, Ferroelectrics and Frequency Control, vol. 61, no. 11, 2014.

14. The research has been done in the area of CS and video applications. Having in mind that...
gathering a complete and comprehensive dataset in transportation systems is quite a challenging task, due to several external and internal sensor equipment and data storage limitations. It is shown that the Compressive Sensing (CS) approach can be efficiently applied to extract vehicle motion features using a limited dataset from the video image. The experimentation has been done on the real video sequences taken from the Philadelphia highway for the purpose of automatic video control and traffic surveillance. The results are collected and the paper has been submitted to the Automatika - Journal for Control, Measurement, Electronics, Computing and Communications.

15. The hardware architectures for the implementation of the two algorithms developed by the project team: single iteration reconstruction algorithm (SIRA) and gradient based algorithm have been proposed and prepared for the MECO 2015 conference. The architectures are suitable for the FPGA realization and in the following period the research activities will be related to the FPGA implementation of the proposed architectures. The project team has already started activities on the extended algorithms implementation.

16. The method for CS reconstruction of the signals with cosine and polynomial phase modulations is proposed. Due to their complexity, the signals are sparsified using the demodulation procedure prior to the reconstruction. In that sense, the demodulation is performed by using direct parameter search method, for both, cosine and polynomial phase modulations. After the demodulation, signal is reconstructed with three commonly used reconstruction algorithms. It is shown that the algorithm proposed by the project team, succeed in detecting both, polynomial and cosine signal parameters, when small number of signal samples are available. The parameters obtained after the demodulation are then used in re-modulation process, in order to recover original signal. The paper has been presented at the MECO 2015 conference.

17. A Virtual instrument called Statistical performance analyser for Compressive Sensing gradient-based reconstruction algorithm has been designed. It is composed of two main parts. One part is a tool for signal reconstruction based on the gradient algorithm. It offers the possibility to generate various signals through the special panel which is used to set the length, sparsity, percentages of available samples and the ranges of amplitude. Also, a noise with specified variance can be added through this panel as well. The second part of presented instrument is dedicated to the statistical analysis such as calculation of MSE as a function of noise variance or signal sparsity, analysis of MSE and computational time in terms of sparsity and the amount of missing samples. This instrument can be useful for both the research and educational purpose for the area of Compressive Sensing and signal reconstruction. The results are prepared in the form of the paper that is accepted for the presentation at the ELMAR 2015 conference.

18. Another user-friendly Virtual instrument is developed in the form of software tool implementing the algorithms for obtaining sparse TF representation and IF estimation. The software tool is based on a reduced set of ambiguity domain measurements. The focus was on the signals with fast varying IF. In such cases the standard distributions cannot provide satisfactory results and therefore, complex-time distributions are used and implemented within the software. The tool offers the possibility to set up various parameters depending on the nature of test signals. The results are collected and the conference paper has been prepared. The paper is accepted for the presentation at the ELMAR 2015 conference.
tool represents an initial version of the future multi-modular software – Virtual Instrument for Compressive Sensing and the future work will be oriented toward the extension of the software tool.

19. In this period, the watermarking of the MRI images on the Compressive Sensing concept is evaluated as well. The watermark embedding is done in certain, small number of acquired 2D DFT domain coefficients, and image is reconstructed from the acquired samples using CS reconstruction techniques. The watermark spreading onto the neighbouring lines (that belong to the radial mask in 2D DFT domain), is proposed as well, in order to increase robustness of the watermarking procedure. The watermark detection is tested under several types of attack. It is shown that the watermark detection is successful under CS attack, as well as in the noisy environment. The prepared paper is accepted to be presented at the ELMAR 2015 conference.

20. Exploring the possibilities of using different transform basis in CS is an important task, needed to extend the field of Compressive Sensing applications. The paper, proposing Compressive Sensing approach based on the Hermite transform, is prepared for the journal paper and it is currently under review. The Hermite transform by itself provides compressed signal representation based on a smaller number of Hermite coefficients compared to the signal length. In this paper it is shown that, for a wide class of signals characterized by sparsity in the Hermite domain, an accurate signal reconstruction can be achieved even if incomplete set of measurements is used. Advantages of the proposed method are demonstrated on numerical examples.

21. The research on possibilities to apply the Compressive Sensing to the nonlinear modulation phase signals reconstruction was done with the INP Grenoble partners. Also, research on filtering the interferences and unwanted components from multicomponent signals was performed, as well as developing methods for combined Compressive Sensing approach and warping operations. Various tests have been performed to justify the proposed concepts. The results are collected and prepared for the journal paper that is currently under review in IEEE Transactions on signals processing.

22. An analogue-digital hardware solution for implementation of the L-estimate space-varying filtering has been proposed. The considered filter form is based on the robust space/spatial-frequency representation and provides efficient denoising of two-dimensional signals/images corrupted by heavy-tailed noise. Moreover, for images with fast varying details and textures, the L-estimate filtering outperforms the commonly used filters. In order to make system feasible for practical applications, a fast implementation of L-estimate space-varying filtering is proposed using a combined analogue-digital approach. It provides efficient real-time processing of images corrupted by strong mixed Gaussian and impulse noise. The paper has been accepted for the publication in Circuits, Systems and Signal Processing Journal.

23. The patent “Hardware implementation of combined Compressive Sensing-based image filtering and reconstruction” has been prepared and it is in the final stage before submission to the Patent Office in Slovenia. The patent has been prepared with the Slovenian partner -
University of Ljubljana. The invention presents a hardware design for combined image filtering and reconstruction approach based on the idea of Compressive Sensing principles. The system has two filtering modules: one module for treating images corrupted by Gaussian and impulse noise and the other module is for the reconstruction of compressive sensed image data. One of the two available scenarios can be selected: image-filtering-then-reconstruction approach or direct-image-reconstruction. For the impulse noise, the filtering module contains the L-estimate filtering approach while the Gaussian noise filtering module contains the random subsampler. The final part of the hardware is a reconstruction module, based on a DCT optimized gradient reconstruction algorithm used to recover entire image from a small amount of randomly available pixels.

**The potential impact and use of main results achieved so far:**

Based on the achieved results and the developed algorithms and solutions, the patent for the hardware implementation of the reconstruction algorithms for images ("Hardware implementation of combined Compressive Sensing-based image filtering and reconstruction") is prepared and its submission is in the final stage. It is important to note that the patented solution has a potential to become a part of the error resilience codecs in the future. Error resilience codecs are part of the existing multimedia standards and are used for recovering the missing information in the data. Namely, during the transmission, significant amount of information can be lost or image can be degraded. This information has to be recovered, and for that purpose the proposed hardware solution with included software support can be used. Our solution can be implemented within those codecs, improving the information recovering. Note that the patent submission was not initially planned by the project. However, based on the suggestions of the World Bank experts, the project team developed the hardware prototype for Compressive Sensing reconstruction and presented the design in the form of patent application.

Also, there is an open possibility to incorporate in the future some of the developed solutions into the Image based Systems for tracking of insects concentration, and thus to improve and facilitate this application on market, with the cooperation of the industry partner. The initial results are already prepared and there is a possibility to extend the collaboration with other companies providing solutions in this field.

The CS can also be used for recovering missing pixels or entire blocks in the images that appear as a consequence of degradation during the image/video transmission. This mean that there is an open possibility to use the developed solutions into digital TV applications for the reconstruction of erroneous image blocks appearing as a consequence of video transmission problems.

The web-based application for CS data reconstruction is launched. It includes various scenarios and solutions for reconstruction of both 1D and 2D signal (images including the demanding natural images), with an arbitrary number of missing data. The web based application can be used by many users simultaneously. It is important to note that user does not need to have knowledge about the algorithms that are implemented. The application is adapted to the open-source
software that does not require any type of the licence in order to be completely independent (especially for commercial use). This application is also very suitable for educational purposes, since can be used in the computer labs worldwide as an educational tool. It can be also used as an individual tool for data recovering for the users that are not familiar with concepts behind, but can be used by professionals in the research filed of interest for testing and examination. Having in mind the web-based implementation, it can be incorporated in many different solutions for the reconstruction of data in real applications (e.g. medical imaging applications, natural images restoration, reconstruction of different types of 1D data).

The next stage is the implementation of web-based application into wider solution called ECHO platform, which is done in cooperation with the Slovenian partner. In June 2015, the project members will visit University of Ljubljana in order to finalize modalities about the implementation of the algorithms that will be included in the platform. The platform is a user friendly tool, where each user can test different types of algorithms working with different types of data. Platform is cloud-based and therefore is available to a great number of users which might bring a significant impact to the project. This platform will also include a set of complementary files containing lectures, training materials, explanation of some basic concepts, etc. The user can do testing on the existing data, or he can upload his own data (e.g. image with missing blocks, lines or pixels), do the reconstruction and end up with a recovered data. The platform can also make a wider impact since it can be a part of the educational programs.

During the 2012-2014 years, the project team was working on implementation of the TV-WEB project - deliver Internet content to those who do not usually use Internet services and who have no broadband connection. The idea was to use the free digital terrestrial television (DTT) broadcasting frequency spectrum capacities for transmitting selected Internet content (such as news, e-services etc.) and ensure a sort of Internet experience via TV devices to certain less advantaged segments of the population, or those in rural areas without broadband access. The ideas and solutions developed within CS ICT project can be combined with the solutions from the TV WEB project, mainly in recovering the information that is missing or is being damaged during the transmission. The CS ICT project team together with the Slovenian partner has started finding the modalities to possibly combine the solutions from these two projects.

Another important impact is done though the dissemination of the new Compressive Sensing theory and algorithms for signal reconstruction covered by this project. Namely, as a new concept already finding its place in the world of technology, it is a great impact to build our position in the region and abroad as a center highly dedicated to this area. Accordingly, Prof. Dr Srdjan Stanković has a role of invited speaker at the MECO 2015 conference, bringing all benefits, challenges and current achievements in front of the large audience.

Also, the whole session at the conference will be dedicated to the topics of the project – Compressive Sensing and its application in different fields of multimedia and signal processing, which brings this area in the focus of research and innovation interests.

One of the main impacts on the educational system in Montenegro is done through the engagement of a group of graduate students to work on the development of solution for Compressive Sensing and its applications within their study courses. As a result of intensive training made by our professors and team members during five months, the students were able to write the conference papers by comprising the results they achieved. The material for 9 scientific papers has been
prepared and the papers are going to be presented at the MECO 2015 conference in June 2015. There is a growing interest among students to continue working in this field during their master and PhD studies. This is an important aspect for the development of research capabilities at the University of Montenegro. Also, this is a great chance to engage more young students in research, which is one of the main strategies for the further development of our university and education system.
### Overview of project objectives for the period

Please provide a short overview of the project objectives for the reporting period in question, as stated in Annex 1 of the Grant Agreement. (These objectives are required so that this report is a stand-alone document). Suggested length 1 page maximum.

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<th>The main objectives planned for this reporting period were:</th>
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<td>- Patent preparation: The patent for the digital image processing and filtering has been prepared and is in the final stage;</td>
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<tr>
<td>- Development of new solutions for the Compressive Sensing reconstruction algorithms and applications: various new reconstruction algorithms have been defined, tested and implemented, including the adaptations for the variety of real-world signals and applications.</td>
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<td>- The work on developing hardware for the CS reconstruction algorithms has been mostly finished; The next phase will include the implementation on hardware board.</td>
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<td>- The Virtual Instrument which implements CS reconstruction algorithms for 1D and 2D signals reconstruction has been developed;</td>
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<tr>
<td>- Another Virtual Instrument in the form of software tool which implements CS-based instantaneous frequency estimation algorithms is developed in its first phase and will be extended and improved in the next period.</td>
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**Meetings and events:**

- Prof. Dr Cornel Ioana: Study visit to Podgorica, Montenegro, from 6th to 13th December, 2014. One of the major goals of this visit was to introduce young researches into his research, to become familiar of the specific research activities and achievements at the INP Grenoble, provide mutual exchange of knowledge in the field of Compressive Sensing and gain practical experience that has been developed within the partner institution. The special attention was paid to the Compressive Sensing in the warping operations, and use of the CS techniques for the non-linear phase modulated signals and in the time warping operations.

During this visit, Prof. Ioana provided intensive trainings related to the Compressive Sensing and its application in non-linear phase modulated signals. Also, the possibility to combine the Compressive Sensing and the warping operators has been discussed as well. Namely, the underwater mammal vocalizations that can be modelled by non-linear time-frequency structures. Generally, they are often recorded with echoes that are due to the reflections with the sea’s surface and bottom and they also overlap in time and frequency which makes them really difficult to track and characterize. Their analysis is of great interest for detection and classification purposes. The possibility to combine the properties of the warping transform with the concept of the Compressive Sensing in order to provide a more accurate characterization of non-linear time-frequency structures in terms of the estimation of their parameters has been discussed during the visit.
- Prof. Dr Gabriel Vasile: Study visit to Podgorica, Montenegro, from 6th to 13th December, 2014. The goal of this visit was to introduce young researches into his research activities and achievements at the INP Grenoble and to provide mutual exchange of knowledge in the field of Compressive Sensing. The special attention was paid to the combination of the CS approach in the radar signal analysis (Synthetic Aperture Radar and Remote Sensing field). During this visit, some problems in radar applications were identified and possible fields of CS application were addressed, as well. He presented achieved results in telecommunication applications, as well. The use of the Fast ICA for deriving non-coherent polarimetric decompositions and Compressive Sensing algorithms for blind source separation for spaceborne synthetic aperture radar has been discussed during the visit. Also, research related to the Compressive Sensing techniques based on fast MST for autofocusing and cleaning was initiated. Project team investigated different applications of the proposed techniques in the fields of acoustic signal processing for active monitoring of river environment (an experiment close to Grenoble, France is still on going for the wild salmon survey).

- Study visit of the Prof. Dr Irena Orović to INP Grenoble, from 27th December 2014 to 27th January 2015., for the purpose of training to the INPG laboratories on the topic of CS and Emerging technologies in West Eur. Labs. The study visits was dedicated to intensive study and training sessions, in order to gain practical experience that has been developed within the partner institution. One of the major goals of this visit was to provide mutual trainings between INP Grenoble and UoMFEE staff members, as well as exchange of knowledge in the field of Compressive Sensing. Prof. Orović exploited the chance to organize several meetings with the industry companies in Grenoble, with the aim to discuss about possible future collaboration with industry and to disseminate the CS ICT project – the idea of the project and the results achieved so far. Meetings with several private companies from Grenoble have been organized, in order to promote project to the industry sector and to discuss about possible collaboration, and to extend list of practical applications where the project results and outcomes may be used.

Related to the research part of this visit, the research on possibilities to apply the Compressive Sensing to the nonlinear modulation phase signals reconstruction was done. Also, research on filtering the interferences and unwanted components from multicomponent signals was performed, as well as developing methods for combined Compressive Sensing approach and warping operations. Various tests have been performed to justify the proposed concepts. The results are collected and prepared for the journal paper that is currently under review:


- Meeting with the CS-ICT project participants, Ljubljana, Slovenia (14th - 16th February, 2015). The purpose of the meeting was presentation of the project work plan and objectives in details, explaining each specific segment of project obligations (including the project management and reporting rules and obligations), scientific and innovation research area related to the project topic, outcomes with all the state of the art achievements, existing algorithms and results. Also, cooperation with the industry is discussed as well (application of the CS to the pest monitoring, i.e. using CS to reduce size of images that are needed to count the number of bugs caught in the trap; application of the CS in recovering images that are damaged during the transmission – e.g. whole blocks or image lines are damaged or missing. CS will be used to recover those missing blocks, lines or pixels.).

- Prof. Cornel Ioana: Study visit to Podgorica, Montenegro, from 11th to 16th May, 2015. Study visit was
organized for the purpose of intensive trainings of the young researches particularly, in order to exchange knowledge and experience in the Compressive Sensing field and to identify possible fields of application using Compressive Sensing approach. This visit is a continuation of Prof. Ioana last visit in December. Through this study visit and intensive trainings that Prof. Ioana prepared and performed, the researchers from the UoMFEE increased their knowledge about signal processing algorithms and approaches, particularly for radar signals and time warping operators.

### Overall work progress and achievements during the period

**Please provide a concise overview of the overall progress of the project towards objectives and indicate the main achievements and any main issues that have arisen in this last period. Suggested length 1 page maximum.**

**In addition, please provide an updated Gantt chart as a separate document.**

After one year of project implementation, we succeed to realize most of the activities specified in the project application including some additional and advanced activities that were not planned initially. It means that almost all specified deliverables has been provided at least in the first version (others are finalized), and will be improved and possibly extended in the future activities.

The detailed list of the achievements during the period December 2014 – June 2015 follows:

- The laboratory Compressive Sensing and Emerging Technologies is established. The research team is engaged in intensive research and is continuously trained in the Lab.
- The equipment purchase is in the final stage and we expect that all equipment will be delivered within next several weeks.
- The contracts with the research staff have been renewed and contracts with the new staff have been concluded. At the moment, 19 researchers and developers are actively involved in the project. Among them, there are 5 PhD students, 2 MSc students and 1 post-doctoral student. Two additional young researchers are employed, as it was planned – one as UoMFEE staff and the other as a PhD student engaged by an external procedure.
- The project web site has been designed and launched. The publications from the beginning of the project have been uploaded, as well as implemented activities and list of project team members. The demo version of the tool for CS reconstruction algorithms testing has been incorporated in the web site.

- The mobility programme for knowledge and skills exchange, from December 2014 to June 2015, have been realized through three study visits:
  1. Prof. Dr Cornel Ioana study visit to Podgorica, Montenegro, from 6th to 13th December, 2014. Intensive trainings to the young and senior researchers have been provided.
  2. Prof. Dr Gabriel Vasile study visit to Podgorica, Montenegro, from 6th to 13th December, 2014. Prof. Vasile provided intensive trainings (for young and senior researchers) in radar signal analysis.
  3. Study visit of the Prof. Dr Irena Orović to INP Grenoble, from 27th December 2014 to 27th January 2015. Intensive study and training sessions have been organized; One journal paper, prepared together with the INP Grenoble research team, has been finalized; Several meetings with the industry
companies in Grenoble have been organized.

**Overall scientific achievements:**

- **19 scientific papers published in the leading scientific journals,**
- **5 book chapters,**
- **2 books prepared,**
- **14 papers presented at the international conferences,**
- **6 papers that are under review in the leading scientific journals and**
- **9 student papers prepared for the presentation.**

- Several new algorithms for Compressive Sensing are developed and new applications are addressed as well, showing remarkable performance compared to the some of the existing methods:
  - gradient algorithm for 1D signal reconstruction has been defined;
  - the modification of the gradient algorithm for 2D signal reconstruction has been proposed;
  - A Compressive Sensing approach based on the Hermite transform;
  - New algorithm for CS reconstruction in Hermite transform domain is proposed;
  - A new method for watermarking of magnetic resonance images is proposed;
  - CS method providing sparse time-frequency representation for signals with fast varying instantaneous frequency (radars, musical signals, etc).
  - CS approach for extracting vehicle motion features;
  - CS reconstruction of cosine and polynomial phase modulated signals

- Several innovative software products and practical solutions specified in the project application have been developed:

  - **1 Patent**
  - **2 software – Virtual Instruments for CS reconstruction**
  - **1 web-based application**
  - **Application within the ECHO platform (initialized)**
  - **2 Hardware architecture for CS reconstruction**
  - **1 Hardware for L-estimate image filtering**

The patent “Hardware implementation of combined Compressive Sensing-based image filtering and reconstruction” has been prepared in English language, translated to the Slovenian language, revised and will be submitted to the Patent Office in Slovenia. It is a hardware design for combined image filtering and CS reconstruction approach and provides two possibilities for reconstruction: image-filtering-then-reconstruction approach or direct-image-reconstruction. This patented solution has a potential to become a part of existing multimedia standards within error resilience codecs that are are used for recovering the missing information in the data. Our solution can be implemented within those codecs, improving the information recovering.

Two hardware schemes have been developed: one for the gradient based algorithm and the other for single (and multi) iteration reconstruction. The architectures are suitable for the
FPGA realization and it is important to note that the activities on FPGA realization are already initiated, as well as preparation for the verification of the solution at the Altera platform.

An analogue-digital hardware for L-estimate space-varying filtering has been proposed. The considered filter form is based on the robust space/spatial-frequency representation and works in cases of heavy-tailed noise. A combined analogue-digital approach is proposed in order to provide an efficient real-time processing of corrupted images.

Development of a Virtual Instrument that incorporated algorithms for 1D and 2D signal reconstruction, with the possibility to generate various signals through the special panel which is used to set different signal parameters. Also, it has part for statistical analysis. The instrument can be useful for both the research and educational purpose for the area of Compressive Sensing and signal reconstruction.

Another Virtual instrument is developed in the form of software tool implementing the algorithms for obtaining sparse TF representation and IF estimation, dealing with a reduced set of signal samples and with signals that has fast changes of their phase function. The tool offers the possibility to set up various parameters depending on the nature of test signals.

Implementation of CS reconstruction algorithms in the ECHO platform has been initiated, in cooperation with the Slovenian partner. The adaptation of the algorithms for the implementation on the platform, modification and adaptation for the open-source software without requiring any type of licence, adaptation for the multi user (and user who does not have knowledge related to the algorithms) purpose, have been done, and required a significant time to be finished. One version of the tool that will be included in the ECHO, is implemented on the CS ICT project website.

- During the period December 2014 – June 2015, three study visits have been organized, one management meeting and several Skype meetings with the project partners, weekly meetings with the UoMFEE project team. The papers for three conferences (ELMAR 2015, MECO 2015 and CoSeRa 2015) have been prepared an accepted for publication.
Individual Work packages progress

For each active work package please provide the information below. Additional notes have been supplied below for Management and Dissemination work packages. Suggested length ½ page maximum per Work Package.

- A summary of progress towards objectives and details for each task;
- Highlight clearly significant results;
- If applicable, explain the reasons for deviations from the original work plan and their impact on other tasks as well as on available resources and planning;
- If applicable, explain the reasons for failing to achieve critical objectives and/or not being on schedule and explain the impact on other tasks as well as on available resources and planning (the explanations should be consistent with the declaration by the designated representatives of Leads Institution);
- A statement on the use of resources, in particular highlighting and explaining deviations between actual and planned person-months per work package and per partner;
- If applicable, propose corrective actions.

WP1: The laboratory for Compressive Sensing and Emerging Technologies is established and fully operative. The research team is engaged in intensive research and is continuously trained in the lab. The laboratory has already been recognized in the region. Several trainings for young and senior researchers have been organized in the lab. We have visits from the researchers from the region (Croatia). The visit for the purpose of training and knowledge exchange between our researchers and researchers from the China (Nanyuang university, Zhejiang University, Hangzhou Normal University) has been planned for the next period. The center has an educational purpose as well, and it is attractive for the graduate and postgraduate students from our and from the other countries. Two postgraduate students from the INP Grenoble are currently in the lab, doing their internship related to the master thesis. Also, in the past period we have intensive 5 months trainings in the lab, for the UoMFEE postgraduate students. The trainings were related to the Compressive Sensing filed and resulted in the preparation of 9 scientific papers that will be presented at the MECO 2015 student session. In the first period of the project realization, two trainings for young researchers by the senior researchers from the UoMFEE and the Grenoble INP researchers have been organized, as well as training on biomedical applications by researcher from the University of Pittsburgh.

Supported by numerous scientific publications, the Research Laboratory for Compressive Sensing and Emerging Technologies is intensively growing research centre and is going toward becoming the backbone of the scientific development in the region. Currently there are just a few attempts dealing with Compressive Sensing applications in the region, while it has already become the topic of crucial efforts abroad. The laboratory will be at the disposal of other research from Montenegrin and foreign research institutions, for joint research work and further innovative developments.

The equipment procurement is in the final stage.
WP2:

- External meetings and study visits (definition of the training plan for all project participants, communication with all researchers involved in the project regarding the mobility periods, conference participation plan for all project participants) were organized.

- Several study visits have been organized in this period:
  
  - Prof. Dr. Cornel Ioana was in the study visit to Podgorica from 6th to 13th December, 2014.
  
  - Prof. Dr Gabriel Vasile was in the study visit to Podgorica from 6th to 13th December, 2014.
  
  - Prof. Dr Irena Orović was to the study visit to INP Grenoble, from 27th December 2014 to 27th January 2015, for the purpose of training to the INPG laboratories on the topic of CS and Emerging technologies in West Eur. Labs.
  
  - Prof. Dr Cornel Ioana was in the study visit to Podgorica from 11th to 16th May, 2015, for the purpose of intensive trainings of the young researches particularly, and identifying possible fields of application of the Compressive Sensing approach.

- Management meetings with the Slovenian partners were organized in Ljubljana, Slovenia (14th - 16th February, 2015). Project team discussed about the further development of project activities and common topics/points of interest that will be further proceeded and investigated toward the developed of joint multimedia application, as well as about management activities.

WP3:

The activities related to the WP3, from June 2014 to May 2015, are verified by 19 scientific papers published in the leading scientific journals, 5 book chapters, 2 books prepared, 14 papers presented at the international conferences, 6 papers that are under review in the leading scientific journals and 9 student papers prepared for the presentation. The detailed research activities are listed in the following:

- The second edition of the Multimedia Signals and Systems book. The book is already submitted. It covers mathematical transformations in signal processing, audio, image and video processing and compression algorithms, protocols used in multimedia, algorithms and techniques for protection of the different types of digital content. The whole chapter is dedicated to the Compressive Sensing: basics of the CS, commonly used algorithms in CS and algorithms that are developed during the project. It is important to note that first edition of the book had envious distribution and we had several thousand of the book sold, through international publisher “Springer”. Therefore, we expect a greater distribution from the second, expanded and improved edition of the book.

- The chapter dedicated to the Compressive Sensing in Digital Signal Processing textbook by Ljubiša Stanković, was prepared during this project period. The chapter is authored by Ljubiša Stanković.
Srdjan Stanković, Miloš Daković and Irena Orović. This chapter includes a review of Compressive sensing techniques together with thorough explanation of basic concepts from the engineering point of view and numerous examples ranging from basic ones to the very advanced ones.

-The research in the area of sparse solution uniqueness has been performed in this period. This work was done with the voluntary help of Professor Ljubiša Stanković. Few theorems important for solution uniqueness are formulated and proved. Research results are summarized in the scientific paper.

- The theoretical and experimental results of analysis of signals sparse in the domain of Hermite expansion, and the application of the CS on such signals have been prepared and the paper has been submitted to the scientific journal. The Hermite functions have been used as a suitable basis for representation and compression of QRS complexes of ECG signals. These signals are important for diagnosis and medical treatment and application in compression algorithms shows that the reconstruction of ECG signals can be done using a few Hermite coefficients.

- The research on CS in video application has been performed as well. Various sensors have been applied in transportation engineering to gather important traffic parameters. Gathering a complete and comprehensive dataset is quite a challenging task, due to several external and internal sensor equipment and data storage limitations. It is shown that the Compressive Sensing (CS) approach can be efficiently applied to extract vehicle motion features using a limited dataset from the video image. A total of three different traffic conditions were examined to fully evaluate the developed algorithm comprehensiveness. The dominant velocities estimated from a complete video dataset and CS-based approach, with a limited dataset, were compared. The results are collected and submitted to the Automatika - Journal for Control, Measurement, Electronics, Computing and Communications and it is currently under review.

- A Compressive Sensing (CS) reconstruction method for polynomial phase signals is proposed. It relies on the Polynomial Fourier transform. Polynomial phase signals are not sparse in commonly used domains such as Fourier or wavelet domain. Therefore, for polynomial phase signals standard CS algorithms applied in these transformation domains cannot provide satisfactory results. In that sense, the Polynomial Fourier transform is used to ensure sparsity. The proposed approach is generalized using time-frequency representations obtained by the Local Polynomial Fourier transform (LPFT). The theory is illustrated on examples. Results are collected in the form of the scientific paper and it is submitted IEEE Transactions on Signal Processing, where it is under review currently.

- A method for the reconstruction of sparse signal which reconstructs the remaining missing samples/measurements is recently proposed. It is based on the adaptive gradient-based algorithm in the time domain. The available samples are fixed, while the missing samples are considered as minimization variables. Also, an improvement of the algorithm is proposed by introduction of a new criterion for the parameter adaptation, based on the gradient direction angles. It improves the algorithm computational efficiency. A theorem for the uniqueness of the recovered signal for given set of missing samples (reconstruction variables) is presented. The methods are illustrated on statistical examples. The results are collected in the scientific paper form. The paper is currently under review.

- The paper related to the combination of the Compressive Sensing and time-frequency distributions is
accepted for the publication in leading scientific journal. Complex time distributions are used for highly non-stationary signals. The aim of this combination is providing sharply localized representation of the signal.

- The procedure for the watermarking of the Magnetic Resonance images has been proposed. The procedure is tested under several attacks. It is shown that the proposed procedure is robust under Compressive Sensing attack. The results are summarized in the scientific paper.

- An analogue-digital hardware solution for implementation of the L-estimate space-varying filtering has been proposed. It provides an efficient denoising of two-dimensional signals/images corrupted by heavy-tailed noise. Moreover, for images with fast varying details and textures, the L-estimate filtering outperforms the commonly used filters. In order to make proposed solution feasible for practical applications, a fast implementation of L-estimate space-varying filtering is proposed using a combined analogue-digital approach. It provides an efficient real-time processing of images corrupted by strong mixed Gaussian and impulse noise.

- Strategy for wet snow detection using multitemporal SAR data has been proposed. The proposed change detection method is primarily based on the comparison between two X band SAR images acquired during the accumulation (winter) and the melting (spring) seasons, in the French Alps. The plausibly modified assumption of the wet/dry snow backscattering ratio, the implicitly introduced spatial correlation between the wet snow areas, and the possibility to vary the level of confidence of the wet snow binary maps by thresholding the obtained probability map, are altogether the supplements brought by the introduced stochastic approach to the ensemble of change detection techniques in snow mapping.

WP4:

- The hardware design for combined image filtering and reconstruction approach based on the idea of Compressive Sensing principles has been done. The system comprises two filtering modules for treating images corrupted by Gaussian and impulse noise and the reconstruction module for CS image data. The user may select one of the two available scenarios: image-filtering-then-reconstruction approach or direct-image-reconstruction. The patent for this system is prepared and its submission is in the final stage.

- The activities on the hardware implementations have been intensively performed. Two hardware schemes have been proposed: Hardware for single iteration reconstruction algorithm and hardware for the gradient based algorithm. FPGA implementation of the single (and multi) iteration reconstruction algorithm hardware has been initiated. Also, the verification of the results will be done at the Altera development board. The equipment procurement is in the final stage and we are expecting that the board will be purchased soon. The project team actively works on preparation (in Quartus software) hardware scheme for verification at the development board.
- The development of analogue-digital design hardware for digital image processing and filtering has been finished during this period.

- The part of the software tool, a Virtual Instrument that contains algorithms for the 1D and 2D signals reconstruction, has been finished. It is completely operative but also gives the opportunity to include more algorithms for 1D and 2D signal reconstruction, in order to compare results and to test the reconstruction performance. The results are collected and the paper for the scientific journal is in the preparation. The overview of the Virtual Instrument is given in the sequel.
Virtual Instrument for 1D and 2D signal reconstruction

The first phase of the Virtual Instrument implementation for the CS based instantaneous frequency estimation and for obtaining sparse time-frequency representation is finished. The results are collected in form of the conference paper that will be presented at the ELMAR 2015 conference. The overview of the instrument is given in the figures below. The next phase of the Virtual Instrument implementation includes its extension (implementation CS reconstruction when missing samples are part of the autocorrelation function, e.g. of the Wigner distribution).
Virtual instrument for obtaining sparse time-frequency representation and instantaneous frequency estimation

-The project team, together with the Slovenian partner, worked several months on the preparation and adaptation of the algorithms that will be included in the ECHO platform (a web-based, multimodal open-source system for the reconstruction of the compressive sensed signals, using developed algorithms for 1D and 2D signals).

WP5: - The web site of the project has been released (web site address: http://www.cs-ict.ac.me/). It contains information about research group and our partners. Also, list of publications has been regularly updated on the web site. The tool for testing CS reconstruction algorithms (that will be implemented within the ECHO platform) has been put on the website as well. List of organized events (with images) can be founded on the site as well. Within the website, the tool that is going to be included in the ECHO platform, is implemented as well. The tool allows user to test different algorithms, on different signals, without having the knowledge about the Compressive Sensing and algorithms. The reconstruction with different number of available samples can be performed and reconstruction results can be compared. Quality of the reconstruction can be measured with different parameters: mean square error and signal to reconstruction ratio. Also, number of iterations for the reconstruction is displayed as well as reconstruction time. For 2D signals, the cases when missing samples are in the form of the entire line or block are implemented, along with the case when the missing samples are randomly distributed within the image. Number of missing lines/block can be chosen as well. Several screen shots of the web site and the tool are given in the sequel.
The front page of the web site
The DEMO part of the web site, used for on-line testing developed algorithms
### Gradient algorithm for image reconstruction — results

<table>
<thead>
<tr>
<th>Iteration</th>
<th>N</th>
<th>Missing pixels</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>742,166</td>
<td>12,7398 [dB]</td>
</tr>
<tr>
<td>10</td>
<td>229,639</td>
<td>21,6657 [dB]</td>
</tr>
<tr>
<td>15</td>
<td>1,49531</td>
<td>24,7522 [dB]</td>
</tr>
<tr>
<td>20</td>
<td>1,12537</td>
<td>21,5647 [dB]</td>
</tr>
</tbody>
</table>

Elapsed time is 21.7095 seconds.

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### Gradient algorithm for image reconstruction — results

<table>
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<tr>
<th>Iteration</th>
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<th>Missing pixels grouped in 5x5 blocks</th>
</tr>
</thead>
<tbody>
<tr>
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<td>122,122</td>
<td>5,62129 [dB]</td>
</tr>
<tr>
<td>10</td>
<td>122,122</td>
<td>23,1999 [dB]</td>
</tr>
<tr>
<td>15</td>
<td>122,122</td>
<td>34,9885 [dB]</td>
</tr>
<tr>
<td>20</td>
<td>122,122</td>
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</tr>
<tr>
<td>25</td>
<td>122,122</td>
<td>35,9167 [dB]</td>
</tr>
<tr>
<td>30</td>
<td>122,122</td>
<td>23,7051 [dB]</td>
</tr>
<tr>
<td>35</td>
<td>122,122</td>
<td>35,4159 [dB]</td>
</tr>
<tr>
<td>40</td>
<td>122,122</td>
<td>35,1647 [dB]</td>
</tr>
<tr>
<td>45</td>
<td>122,122</td>
<td>35,7051 [dB]</td>
</tr>
<tr>
<td>50</td>
<td>122,122</td>
<td>35,5101 [dB]</td>
</tr>
</tbody>
</table>

Elapsed time is 17.4950 seconds.

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**Different scenarios and reconstruction of 2D signals (missing pixels distributed randomly - upper figure, missing pixels grouped in blocks – lower figure)**
WP6: The main part of the management activities during this period was related to the communication activities with the HERIC office, Ministry of Science of Montenegro and the technical support unit from the Ministry of finance of Montenegro. The equipment procurement procedure has been prepared and it is almost finished. The communication with the HERIC office included preparation of documents that are required for the financial project management (Tables of costs - travel costs and costs of stay for the project meetings and researchers’ mobility), procedure for contracts renewal, preparation of the training plan for the second project year and preparation of the documents for the modifications in the project.

WP7: The internal quality control was performed during this period, mainly through the monthly reports which were submitted to the project coordinator. Also, meetings with the Project Leader have been organized each week, and the project team discussed about results and dynamics of the project. The study visits from experts and researchers from other partner institutions were used also as opportunities to evaluate the quality of the work plan, quality of the results, and the research strategy.
For the Project Management work package please include the following:

- **Partnership management tasks and achievements;**
- If applicable, problems which have occurred and how they were solved or envisaged solutions;
- Changes in the partnership, if any;
- List of project meetings, dates and venues;
- Project planning and status;
- Impact of possible deviations from the planned milestones and deliverables, if any;
- The section should also provide short comments and information on co-ordination activities during the period in question, such as communication between partners, possible co-operation with other projects/programmes etc.

**Partnership management tasks and achievements:** The main part of management activities was related to the communication activities with the HERIC office, Ministry of Science of Montenegro and the technical support unit from the Ministry of finance of Montenegro. The meetings with the UoMFEE project team were organized each week. During the meetings, the team discussed about research results, spending forecast, mobility periods, the conference participation plan and other planned activities for the next period, etc. Also, several meetings with the project partners from Slovenia and Grenoble were organized (mostly by Skype). Other management activities during the period December 2014 - June 2015 were focused on the preparation of documents that are required for the financial project management, in the first line the documentation related to the Tables of costs for the project meetings, researchers' mobility and preparation of the research contracts for the staff involved in project implementation. During the May 2015, the meeting with the World Bank representatives has been organized in the Laboratory for Compressive Sensing and Emerging Technologies, UoMFEE.

- **If applicable, problems which have occurred and how they were solved or envisaged solutions;**
  - The problems appearing during this project period, similar as in the first period of the project implementation, were mostly related to the administrative procedures - the exact budget predictions and training plans for different events (e.g. the number of participants at the scientific conference depends on the number of papers that will be accepted for the presentation). Consequently, it is impossible to predict how many of the staff members will participate at the conference. Therefore, we had changes in the budget predicted for these events, as well as changes in the training plan (which requires additional administration procedures).

- **Changes in the partnership, if any;**
  - No changes in the partnership

- **List of project meetings, dates and venues;**
  1) Study visit to Podgorica for training and developing practical solutions in Compressive Sensing (Prof. Dr Cornel Ioana, December 2014).
  2) Study visit to Podgorica for training young staff and introducing project team members
with the current research topics and achievements of the INP Grenoble team (Prof. Dr Gabriel Vasile, December 2014).

3) Study visit to INP Grenoble for training, professional expertise and knowledge exchange planned within the project plan (Prof. Dr Irena Orović, 27th December 2014 – 27th January 2015).

4) Management meeting to Slovenia with the purpose to present current activities in project development (Prof. Dr Srdjan Stanković, Prof. Dr Irena Orović, February 2015)

5) Study visit to Podgorica for training and developing practical solutions in Compressive Sensing (Prof. Dr Cornel Ioana, May 2015).

6) Meeting with the World Bank representatives (May 2015)

- **Project planning and status**

  Most of the project activities are realized according to the plan.
  - Equipment procurement is almost finished.
  - Participation to the CoSeRa 2015 conference in June 2015 has been planned
  - Participation to the MECO 2015 conference in June 2015 has been planned
  - Also, the web site for the project has been developed (Web site address is: www.cs-ict.ac.me). The site is continuously updated with the recent activities in the project, published and submitted papers, etc. Also, the tool for testing the developed algorithms for 1D and 2D signals has been made and included in the web site.
  - According to the training plan, for the next year the workshop with the researchers from the China and Slovenia has been planned (end of July 2015).
  - Study visit to INP Grenoble for training, professional expertise and knowledge exchange on the topic Compressive Sensing and signal reconstruction algorithms has planned for two young UoMFE researches.
  - One study visit is planned to be done to the University of Pittsburgh, for two researchers from the UoMFE.
  - Participation to the two conferences (ELMAR 2015 and TELFOR 2015) has been planned in the second half of the year.
  - The next management meeting is planned to be organized in the Montenegro, and one workshop where all partners will participate is also planned to be organized in Montenegro.

- **Impact of possible deviations from the planned milestones and deliverables, if any;**

  No significant impacts encountered.

- **The section should also provide short comments and information on co-ordination activities during the period in question, such as communication between partners, possible co-operation with other projects/programmes etc.**

  - In the February 2015, the meeting with Slovenian partners was held in Ljubljana, Slovenia. The purpose of the meeting was presentation of the project work plan and objectives in details, explaining each specific segment of project obligations (including the project management and reporting rules and obligations), scientific and innovation research area related to the project topic, outcomes with all the state of the art achievements, existing algorithms and results. Also, possible
collaboration with industry partners was discussed in the meeting.
- Weekly internal meetings with the UoMFEE project staff were organized, in order to summarize the research results, to define the training plan for all project participants, make the conference participation plan for all project participants.
- Communication with all researchers involved in the project was periodically organized.
- Contracts for engaging researchers on the project and contract renewals were completed in the past period. A detailed research plans for each of researchers for the following period were made. These plans are incorporated into individual contracts.
- The project members continuously communicate with each other through e-mail and Skype. Also, Skype video conferences were organized and discussions about the project results were made. The rest of the activities in this category are related to the daily management of the project, communication with representatives HERIC Office and the Ministry of Science in order to efficiently implement project tasks.
- Two students from the partner institution, INP Grenoble, stay in our lab, from March 2015 to August 2015. They do the research on development of the CS algorithms in multimedia applications (exploring the possibility to adapt gradient based algorithm to work with other transform basis) as well as CS in power systems. During period of their stay, several meeting were organized with the aim to follow their work and give them suggestions and ideas for the continuation of their work.

For the Dissemination work package please include the following:

- **Use of ‘foreground’ and dissemination activities during this period.**
  This should include:
  - List of publications resulting from the project in the period (published or submitted).
  - List of events organised by the project in the period or planned for the next period.
  - List of exploitable results (if relevant): provide a short description and an overview in each case of how the knowledge could be exploited or used in further research. Indicate if Intellectual Property Rights protection measures have been/will be sought (patents, design rights, database rights – include references and any relevant details).

- **List of publications resulting from the project in the period (published or submitted):**

**Leading International Journals and Book Chapters**


**International Conferences**


S. Stanković, I. Orović, T. Pejaković, and M. Orović, “Compressive Sensing reconstruction of signals with sinusoidal phase modulation: application to radar micro-Doppler,” 22nd Telecommunications Forum TELFOR 2014, Belgrade, Serbia


Student papers


List of events organised by the project in the period or planned for the next period.

- **Organized events (December 2014 – June 2015):**
  - Study visit form INP Grenoble to Podgorica (Prof. Dr. Cornel Ioana), December 2014
  - Study visit form INP Grenoble to Podgorica (Prof. Dr. Gabriel Vasile), December 2014
  - Study visit of the Prof. Dr. Irena Orović to INP Grenoble, from 27th December 2014 to 27th January 2015.
  - Meeting with the CS-ICT project participants, Ljubljana, Slovenia (14th - 16th February, 2015)
  - Study visit from INP Grenoble to Podgorica, Montenegro, from 11th to 16th May, 2015. (Prof. Dr. Cornel Ioana)

- **Planned events:**
  - Participation to the COSERA 2015 conference
  - Participation to the MECO 2015 conference
  - Meeting with the CS-ICT project participants, Ljubljana, Slovenia (29/30 June 2015)
  - Workshop with partners from Slovenia and China, 26.07.2015.-05.08.2015, UoMFE
  - Study visit to INP Grenoble for training, professional expertise and knowledge
exchange planned within the project plan, 25.08.2015-10.09.2015, UoMFEE
  o Participation to the 57th International Symposium ELMAR 2015, September 2015, UoMFEE
  o Promo days of our project, October 2015, UoMFEE
  o Workshop for all partners and invited participants, October-November 2015, UoMFEE
  o Regional Conference TELFOR 2015 (Telecommunication Forum), November 2015, UoMFEE
  o Management meeting with the purpose to present current activities in project development, December 2015, UoMFEE
  o Study visit to University of Pittsburgh for training, professional expertise and knowledge exchange planned within the project plan, May 2016, UoMFEE

List of exploitable results (if relevant): provide a short description and an overview in each case of how the knowledge could be exploited or used in further research. Indicate if Intellectual Property Rights protection measures have been/will be sought (patents, design rights, database rights – include references and any relevant details).

1. A patent finalization and activities on its IPR protection are planned for the future period.

2. A closed-form software solution is almost finished. It implements algorithms developed by the project team as well as algorithms commonly used for CS signal reconstruction. This software product can be used for research activities (at the universities), but also as an application software for solving problems in industry. It has the possibility of extending the solution for specific needs and requirements upon the request. The activities on promoting the software, for educational use as well as for the research activities, will be done in the next period. The algorithms and codes are not available and visible to the users since the application performs on the server. Thus we have been taking care about protecting our IPR through additional efforts in application security protection. In the next period we will consider other IPR issue as well.

3. The image reconstruction technique from a small amount of information, that was recently developed, will also be protected through the virtual instrument.

4. Another important exploitation of knowledge is related to the idea to foster the expertise and potential of our new laboratory in order to outgrow into a regional CS center dedicated to the Compressive Sensing and emerging technologies. Namely, having in mind the current situation in Montenegrin higher education and research, where it is indispensable to increase the number of postgraduate students to strengthen their motivation and research capabilities, it is of great importance to build environment capable of attracting new students, scientists and further research funding. Consequently, the project team has developed the program of inclusion for young researchers into emerging Compressive Sensing area through the intensive courses and training followed by the research supervision of students. As a result, a group of 20 students from the University of Montenegro prepared and presented the research papers at the Compressive Sensing related conference.
5. An important exploitation of knowledge and achievements from this project period will be done through the adaptation of developed solution toward more specific applications in the area of multimedia, communications and biomedical signal processing. In that sense, we expect the next series of publications focused on solving the actual problems in applications using the solid research basis accumulated within the previous research activities.
Deliverables and milestones tables

Deliverables (do not include submission of periodic and final reports in this deliverable report)

Please list all the deliverables due in this reporting period, as indicated in Annex 1 of the Grant Agreement.

<table>
<thead>
<tr>
<th>Del. No.</th>
<th>Deliverable name</th>
<th>WP No.</th>
<th>Nature</th>
<th>Projected delivery date (from Annex 1)</th>
<th>Actual/Forecast delivery date</th>
<th>Comments</th>
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<td>Reports from the Management meeting - Kick off meeting</td>
<td>WP6</td>
<td>R</td>
<td>M12</td>
<td>M12</td>
<td>The reports have been submitted</td>
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<tr>
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<td>WP6</td>
<td>R</td>
<td>M12</td>
<td>M12</td>
<td>The reports have been submitted</td>
</tr>
</tbody>
</table>

If a deliverable has been delayed, cancelled or regrouped with another one, or if its content has been modified, please indicate and explain this in the column “Comments”.

If a new deliverable is proposed, please indicate this in appropriate way in the table, allocating the appropriate ordinal number in the first column and explanation in the column “Comments”.

---

1 Deliverable numbers in order of delivery dates. Please use the numbering convention <WP number>.<number of deliverable within that WP>. For example, deliverable 4.2 would be the second deliverable from work package 4.

2 Please indicate the nature of the deliverable using one of the following codes:
   - R = Report;
   - P = Prototype;
   - D = Demonstrator;
   - O = Other;

3 Measured in months from the project start date.
**Milestones**

*Please complete this table with milestones reached in this reporting period as specified in Annex 1 of the Grant Agreement. Milestones will be assessed against the specific criteria and performance indicators as defined in Annex 1. Please record any deviations in the comments column.*

<table>
<thead>
<tr>
<th>No.</th>
<th>Name</th>
<th>Work packages involved</th>
<th>Achieved? (Y/N)</th>
<th>Planned completion date</th>
<th>Realised completion date</th>
<th>Comments</th>
<th>Means of verification (from Annex 1, table 1.2c)</th>
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<td>1.2</td>
<td>Equipment</td>
<td>WP1</td>
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<td>WP3</td>
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<td>[06.2014]</td>
<td>[05.2017]</td>
<td>The paper publications is done according to the project plan</td>
<td>Published papers</td>
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<td>Analysis of the application areas</td>
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<td>[05.2015]</td>
<td>Implementation strategy completed</td>
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<td>[05.2015]</td>
<td>[05.2017]</td>
<td>The first version of software products has been released and it is in the testing phase.</td>
<td>Software released and validated by the user group</td>
</tr>
<tr>
<td>4.2</td>
<td>Developing a hardware design using programmable logical devices</td>
<td>WP4</td>
<td>Y</td>
<td>[05.2015]</td>
<td>[03.2017]</td>
<td>All activities on hardware implementation have been already started and the main part of design is finalized.</td>
<td>Hardware design released and validated by the users</td>
</tr>
<tr>
<td>7.1</td>
<td>Project management activities</td>
<td>WP6, WP7</td>
<td>Y</td>
<td>[06.2014]</td>
<td>[05.2017]</td>
<td>All project management activities are continuously performed according to the plan.</td>
<td>Project has been well managed and the quality has been validated</td>
</tr>
</tbody>
</table>

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4 Indicate how you can confirm that the milestone has been attained. Refer to indicators if appropriate. For example: a laboratory prototype completed and running flawlessly; software released and validated by a user group; field survey complete and data quality validated.
Key activities planned for next reporting period

Please provide a concise overview of the objectives and activities planned for the next reporting period. Indicate if any major issues that have arisen in the last reporting period will be addressed here. Suggested length 1 page maximum.

For the next project period, following activities are planned:

- The important activity for the project dissemination and possible collaboration extending (planned for June 2015) is the invited lecture of the Prof. Dr Srdjan Stanković, at the MECO 2015 conference. Prof. Stanković has an invited speak at the MECO 2015 conference, which is expected to result in attraction of the researchers, working in the digital signal processing, to exchange the ideas and eventually, do the joint work with the UoMFEE project team. The presentation as well as tutorial which is made for this presentation, will be available on the project web site. Except invited lecture, the whole session (student session) was dedicated to the topics of the project – Compressive Sensing and its application in different fields of multimedia and signal processing.

- Special student session has been planned for the MECO 2015 conference. It is result of five month course that has been organized within Multimedia Signals and Systems postgraduate course. With the help and guidance of the project team members, nine scientific papers have been prepared for the presentation at the MECO 2015 conference.

- The participation to the COSERA 2015 conference, planned for the June 2015, is expected to results in strengthening the collaboration with the participants dealing with the radar signal processing. The research results from our project team are going to be presented, and we expect that significant comments and suggestions for future work will be provided by the other researchers working in the same field.

- Meeting with the CS-ICT project participants, Ljubljana, Slovenia (planned for 29/30 June 2015). Some of the activities planned for the meeting are: Presentation of the project work plan, including the project management and reporting rules and obligations, scientific and innovation results and outcomes. Finalizing patent "Hardware implementation of combined Compressive Sensing-based image filtering and reconstruction” and discussion about all administrative details. Discussion about the implementation of CS reconstruction algorithms in the ECHO platform and working on the implementation of new web application for Compressive Sensing and its integration within the ECHO platform

- The preparation of the journal paper, related to the Virtual Instrument for 1D and 2D signal reconstruction.

- Also, the extension of the Virtual Instrument for sparse time-frequency representation and instantaneous frequency estimation is planned, with the new ideas and solutions developed during the past period of the project realization.

- During the next period, the finalization of the hardware for algorithms proposed by project team is planned. Namely, several hardware implementations are planed:

1) Hardware implementation of the single and multi-step algorithm for reconstruction of sparse
signals using threshold based procedure. This hardware will actually include two solutions: the first solution is to reconstruct signal components at once, while the other solution will concern more complex signal cases with far lower number of available samples where desired solution is reached within a few iterations. The work on the hardware implementation in FPGA and its verification on the Altera development board are also planned for the next period.

2) Hardware for the gradient based algorithm for 1D signals – iterative algorithm that is suitable for different types of 1D signals - hardware implementation in FPGA and its verification on the Altera development board

3) Finalization of the hardware and patent for image reconstruction algorithm based on the 2D gradient algorithm – hardware aiming at implementing this powerful algorithm developed within the new laboratory for Compressive Sensing and emerging technologies as a real-time implementation for image based applications

The second edition of the book Multimedia Signals and Systems is prepared for the submission. The final steps related to the submission are planned for the June 2015.

- The book Digital Signal Processing with chapter dealing with the Compressive Sensing is in the final stage and it will be finalized in next several weeks.

- Organization of the workshop in Kotor (end of July 2015) where will participate the researchers from the UoMFEE and partners from Slovenia and China. Our partners (within bilateral project) from China will visit us at the end of July. Therefore, we will use the chance to organize big workshop where we will also invite our partners from Slovenia. Our partners from China are from different universities - Nanyang Technological University, University of Singapore and University of China. The partner institutions from China will present the state of the art research in their fields of expertise, which might lead to new ideas and concepts in our fields of research. The project team will use the opportunity to gather their knowledge and their expertise to get new ideas for development of new approaches.

- Study visit of Miloš Brajović and Andjela Draganić to INP Grenoble for training, professional expertise and knowledge exchange (planned for the August/September 2015);

- Study visit to University of Pittsburgh training and developing practical solutions in Compressive Sensing in biomedical applications, for two researchers form the UoMFEE, is planned for the May 2016.

- Management meeting in Montenegro with the purpose to present current activities in project development and discuss about the activities planned for the next period (planned in December 2015)

- Participation to the ELMAR conference in September 2015 and presentation of the newest results

- Participation to the TELFOR conference in November 2015 and presentation of the newest results

- Workshop for all partners and invited participants in October – November 2015: During the workshop, the researchers will have a chance to become completely familiar with the specific research activities and achievements of each project partner. This workshop will also include the modalities for developing practical applications, the training sessions for young scientists leaded by the experience of senior researchers and
professors. The partner institutions will present the state of the art research in their fields of expertise, which might lead to new ideas and concepts in other fields of research.

**Recommendations to the PMT and MoS (suggested length 1 page maximum)**

- Make any recommendation you find appropriate;
- In addition, you may list the manner in which in your opinion the PMT and MoS can assist in promoting project implementation.

- Promoting the research results during the Days of Science
- Providing contacts with other institutions and companies, in Montenegro and abroad, dealing with multimedia, communications, medical applications with the idea to create a market for the developed (and new) software solutions.
- It would be important that the MoS promotes the software solutions that we are developing in Montenegro and to stimulate our companies to invest and cooperate with academic partners.
REFERENCES


