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COST Action IC1401 (Action 2014-12-10 – Action 2018-12-09)

Memristors: Devices, Models, Circuits, Systems and Applications (MemoCIS)

PROGRESS REVIEW AT MONTH 24

This report assessing the period stated above is submitted by the Rapporteur.

Confidentiality: This report, other than the Summary Assessment, is confidential to the Management Committee and the COST Association (including the Committee of Senior Officials, Scientific Committee and Administration). The Summary Assessment is non-confidential.

Summary assessment of progress (for publication):

The action made excellent progress during first half of its term. All objectives for the reported period are achieved to a high degree of satisfaction. These all contributed to main objective of establishing EU-wide scientific and technologic knowledge platform assisting interdisciplinary interaction of the development of memristor technology and applications. The breadth and depth of interdisciplinary collaboration is evidenced by 22 countries-participants, 166 scientists-participants, 9 companies involved, 10 collaborative grant proposals submitted, 60 papers published in high-impact peer-reviewed journals and conference proceedings, 8 special sessions at international conferences organized.

Over half a hundred scientific achievements are reported, including physical unbiased generation of random numbers with coupled resistive switching devices, electrochemical biosensor base of the memristive effect, memristor-based architecture for High-Radix arithmetic systems, computation-in-memory based parallel adder, oscillation-based slime mould electronic circuit model for maze-solving computations, event-based soft-core processor in a bio-hybrid setup applied to structural plasticity, neuro-morphic learning and recognition with one-transistor-one resistor synapse. Exemplar success is the implementation of a spiking neural network with hafnium dioxide memristive synapses: the network performs unsupervised learning for character recognition based on spike-timing dependent plasticity of the memristive synapses.

The networking produced immediate benefits in preventing unnecessary duplication of research work between different groups by coordinating the existing efforts and setting goals and directions for future work, and helped the community to optimally distribute research tasks, time and personnel costs. Most impacts proposed have been achieved by the Action. These include technological impacts (creating the critical mass in interdisciplinary research, promoting knowledge transfer and cross-fertilisation, facilitating collaboration between research with diverse backgrounds) and societal impacts (ensuring high-level of expertise of the Action partners, and providing the opportunity to initiate conferences). Economic impacts are achieved or nearly achieved, i.e. foreseen in 5-10 years (promoting the technology transfer, creating future computational foundations).

The action is progressing appropriately with excellent achievement of MoU objectives and delivery of MoU deliverables and delivery of multiple valid additional outputs, successfully contributing to the COST mission of COST enables break-through scientific developments leading to new concepts and products and thereby contributes to strengthen Europe's research and innovation capacities.



COST is supported by
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<p>I. Review of Progress</p> <p>MoU objectives</p> <p>All objectives are achieved to a high degree of satisfaction. These all contributed to main objective of establishing EU-wide scientific and technologic knowledge platform assisting interdisciplinary interaction of the development of memristor technology and applications. The Action reports the objective related to consolidation of models and simulation tools and dissemination of know-how for a fast adoption of memristor technology as partially achieved. I would say this is too modest statement. Models, tools and hardware are dynamically therefore there never will be such thing as 'final integration', this is never ending process. In summary, all objectives are achieved.</p>
<p>MoU deliverables</p> <p>Most deliverables are delivered in full. Some show absolutely outstanding progress, e.g. 60 partners were promised but 166 partners achieved. Some deliverables are almost achieved, e.g. 10 companies were planned to include in the networking 9 were included, which is a good result. With regards to scientific missions and research exchanges with the Action, 20 were planned, 12 achieved. This is also a good result, but the Action is invited to analyse if can make even better use of this networking tool, which often leads to direct research results. Very good anyway. There are no danger of any deliverable not being delivered.</p>
<p>Co-authored publications and FP7/ H2020 proposals/ projects</p> <p>Huge number of papers published in high-impact peer-reviewed journals and conference proceedings. Spectrum of journal targeted is very impressive. Distribution of publications between the Working Groups is following: WG1 --- 15 joined, 31 related, WG2 --- 17 joined, 42 related, WG3 --- 21 joined, 24 related, WG4 --- 20 joined, 18 related. Distribution of the journals impact factors is impressive. Obviously, it is too early to count number of citations, cause not enough years is accumulated. With the grant proposals and grants, three grant proposal were submitted, one was funded. Excellent statistics. Moreover, one member of the Action won an ERC Starting Grant, whilst two members won ERC Consolidator grants, in topics that will benefit directly from the outputs of the MemoCIS COST Action.</p>
<p>Additional Outputs and achievements</p> <p>The list of outputs provided is impressive and included 60 'achievements'. Indeed it is too early to understand which of these will be true scientific break-through and which are incremental, however even by looking at the list we apprehend depth and width of the challenge undertake by the Action. This is really impressive. I personally got attract to the following results include physical unbiased generation of random numbers with coupled resistive switching devices, electrochemical biosensor base of the memristive effect and DNA aptamers, memristor-based architecture for High-Radix arithmetic systems, computation-in-memory based parallel adder, oscillation-based slime mould electronic circuit model for maze-solving computations, event-based soft-core processor in a bio-hybrid setup applied to structural plasticity, euro-morphic learning and recognition with one-transistor-one resistor synapse.</p>
<p>General assessment of progress</p> <p>To make the overall assessment of progress: Select the overall level of risk that best corresponds to that of the MoU objectives and deliverables¹ (high/ moderate/ low) at the time the Action was approved and</p>

¹ When assessing achievement of MoU objectives and delivery of MoU deliverables any changes approved by the (Scientific Committee/ CSO) must be considered the base against which the assessment is made.

Select the statement that corresponds to the level of progress with achievement of these objectives, delivery of deliverables and any additional outputs. Policy as well as scientific/ technological outputs and impacts must be addressed.
Correlate the selected options in order to arrive at the overall assessment (which is a result of the combination of achievement level and risk/ ambition level).

	Level of MoU objective achievement, MoU deliverable delivery and additional outputs	General risk/ ambition level of Action MoU objectives and/ or deliverables (at the time of submission)		
		X High	<input type="checkbox"/> Moderate	<input type="checkbox"/> Low
Scientific/ technological and policy outcomes and impact	<input checked="" type="checkbox"/> Action is progressing appropriately with achievement of MoU objectives and delivery of MoU deliverables and delivery of multiple valid additional outputs, contributing to the COST mission of "COST enables break-through scientific developments leading to new concepts and products and thereby contributes to strengthen Europe's research and innovation capacities."	<u>Excellent</u>	Excellent	Very Good
	<input type="checkbox"/> Action is progressing appropriately with achievement of MoU objectives and delivery of MoU deliverables and delivery of at least one valid additional output	Excellent	Excellent	Very Good
	<input type="checkbox"/> Action is progressing appropriately with achievement of all MoU objectives and delivery of all MoU deliverables OR Action is progressing appropriately with achievement of most MoU objectives and delivery of most MoU deliverables AND delivery of at least one valid additional output	Excellent	Very Good	Good
	<input type="checkbox"/> The Action is progressing appropriately with achievement of the majority of MoU objectives and delivery of the majority of MoU deliverables and no valid additional outputs	Very Good	Good	Fair
	<input type="checkbox"/> The Action is progressing appropriately with achievement of half of the MoU objectives and delivery of half of the MoU deliverables.	Good	Fair	Poor
	<input type="checkbox"/> The Action is progressing appropriately with achieving few if any of the MoU objectives and delivering few if any of the MoU deliverables although there is progress with some other valid outputs	Fair	Poor	Fail

	<input type="checkbox"/> The Action is not progressing appropriately with the achievement of any MoU objectives, or delivery of any MoU deliverables or any valid additional outcomes	Poor	Fail	Fail
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II. Review of the Networking	
Added value of the networking	
1. Comment on the Action's description of the added value of the networking	
<p>The action's description of the added value of the network is valid. I endorse the statement that "the networking of this COST Action has enabled cross-disciplinary, cross-geographical interaction of many researchers, thus reducing effort duplication in the European research area". Examples of this unique interaction are indeed very impressive. During the reported period they achieved extraordinary good results. The networking produced also immediate benefits in preventing unnecessary duplication of research work between different groups by coordinating the existing efforts and setting goals and directions for future work. Thus the networking helped the community to optimally distribute research tasks, time and personnel costs. Notably, half of the participating countries were from the Inclusiveness Target Countries. Female representation was also good, nearly 50%.</p>	
2. Assess the validity of the Action's statement regarding the necessity of the added value of the Action networking for the Action co-authored publications:	
<input checked="" type="checkbox"/>	Action statement is valid
<input type="checkbox"/>	Action statement is not valid for the following publications for the following reasons
	<input type="text" value="(specify which publications and justify/ explain)"/>

III. Review of Impacts²	
1. With reference to the definition of impacts in Annex 1 comment on the validity, relevance and significance (in particular importance and timeliness) of the impacts (Scientific/ technological, Economic, Societal) claimed by the Action (in Section I.D of the Achievement Report).	
2. Indicate any additional possible impacts not considered by the Action.	
<p>Most impacts proposed have been achieved by the Action. These include technological impacts (creating the critical mass in interdisciplinary research, promoting knowledge transfer and cross-fertilisation, facilitating collaboration between research with diverse backgrounds) and societal impacts (ensuring high-level of expertise of the Action partners, and providing the opportunity to initiate conferences). Economic impacts are achieved or nearly achieved, i.e. foreseen in 5-10 years (promoting the technology transfer, creating future computational foundations).</p>	
Overall assessment of impacts	
Select the statement that best describes the Action's impacts:	
<input checked="" type="checkbox"/>	Multiple highly significant impacts are reasonably foreseen, at least one of which is already observed [Excellent]
<input type="checkbox"/>	Multiple highly significant impacts are reasonably foreseen for the future OR one highly or moderately significant impact is already observed [Very Good]
<input type="checkbox"/>	One highly significant or multiple moderately significant impacts are reasonably foreseen for the future [Good]

- One moderately significant impact or multiple impacts of low significance is/ are reasonably foreseen for the future OR one impact of low significant is already observed [Fair]
- At least one impact of low significance may occur in the future [Poor]
- No impacts have occurred or can be foreseen to occur in the future [Fail]

IV. Review of Dissemination and exploitation of Action results

1. Assess the effectiveness of the Action's dissemination and exploitation approach.

Academic dissemination approach is very efficient (as judged by a number and quality of papers published and conferences organized); exploitation approach is very good: several companies are involved, collaboration between academia and industry is well-established. It is too early to talk about commercialisation.

Indicate whether each initiative implemented by the Action was effective and added value or not.

Item/ activity	Target audience	Result	Hyperlink	Effective and added value Y/N
Action Website	Action Members, International Research Community, International and Regional Industry	Achieved	www.memocis.eu	Y
Electronic Discussion Forum	Action members, PhD students, Post-doctoral fellows, young researchers	Achieved	http://eceherlfilesvr.ce.ucy.ac.cy/index.php?option=com_kunena&view=category&layout=list&Itemid=198	Y
Two meetings of the Action Partners per year, for internal discussion	Action Members	Achieved	www.memocis.eu	Y
Annual Workshops	Action Members and External Scientists	Achieved	http://eceherlfilesvr.ce.ucy.ac.cy/index.php?option=com_content&view=article&id=17&Itemid=161	Y
Training School	Action Members and their students	Achieved	http://eceherlfilesvr.ce.ucy.ac.cy/index.php?option=com_content&view=article&id=38&Itemid=212	Y
Publications: papers in peer-reviewed journals, conference proceedings, technical reports	Action members, Scientific Community, Policy Makers	Achieved	http://eceherlfilesvr.ce.ucy.ac.cy/index.php?option=com_content&view=article&id=43&Itemid=121	Y
Organisation of Special	Action members, Scientific Community	Achieved		Y

Sessions at Conferences			<ul style="list-style-type: none"> • Special Session on Memristors in IEEE NANO 2015, Rome, Italy, 27-30 July 2015 • Special Session on “Memristor-based Cellular Nanoscale Networks: Theory, Design, and Applications” ISCAS 2015 • Special Session on “Memristors” at Melecon 2016 • Two Invited Sessions on “Memristors” ISCAS 2016(1), ISCAS 2016(2) • Special Session on “Memristor Materials”, MOLARMEET 2016 • Special Session “Memristors for Computing” CNNA 2016 	
Twitter Account for Action (not in MoU)	Action members, scientific community and general public	Achieved	https://twitter.com/MemoCISofficial?ref_src=twsrc%5Etfw	Y
<p>Select which of the following statements best describes the Action</p> <p><input checked="" type="checkbox"/> There were many highly effective Action activities focusing on dissemination³ and exploitation of Action results [Excellent]</p> <p><input type="checkbox"/> All Action activities focusing on dissemination and exploitation of Action results were effective [Very Good]</p> <p><input type="checkbox"/> Most Action activities focusing on dissemination and exploitation of Action results were effective [Good]</p> <p><input type="checkbox"/> A few Action activities focusing on dissemination and exploitation of Action results were effective [Fair]</p> <p><input type="checkbox"/> The activities undertaken focusing on dissemination and exploitation were ineffective [Poor]</p> <p><input type="checkbox"/> The Action did not undertake any valid activities focusing on dissemination and exploitation of Action results [Fail]</p>				

V. Review of Action Success(s)

COST regularly communicates the successes of Actions. Please comment on the validity of the aspect(s) identified by this Action as its greatest successes.

The success illustrated is a demonstration that a spiking neural network with hafnium dioxide memristive synapses can perform unsupervised learning for character recognition based on spike-timing dependent

3

Dissemination activities could include: Action website, co-authored publications listed at Section I.B of Action's Progress Report, other Action publications, attendance at Dissemination Meetings listed at Section II.B.2 of Action's Progress Report.



plasticity of the memristive synapses. This is a technological break-through. All aspects of this success story are valid.

If you believe that another aspect(s) (outcomes and/ or impacts, rather than activities) of the Action should be considered its greatest success(es) please define these below (maximum two).

Description of the success story	Dimension of the success Breakthrough: scientific, technological or socioeconomic Policy implementation (specify which policy) Capacity building)

VI. Review of the management of the Action budget

Funds spent outside of the COST countries

1. If the Action spent funds on STSMs to approved institutions in International Partner Countries (IPC) or Near Neighbour Countries (NNC) and/ or STSMs from an approved institution in a NNC please assess the value of these activities to the Action.

n/a

3. If the Action spent funds on any "Invited Speakers" for meetings and/ or Training Schools or on Dissemination meetings please assess the value these added to the Action

The value of funds spent on invited speakers is excellent (and well justified indeed). Three speakers were invited: Leon Chua (God Father of memristors), Farnood Merrikh Bayat (co-author of memristors based classifiers) and Robert Legenstein (authority in computation and learning in networks of memristive spiking neurons).

General comments on Action management

Action management is appropriate and achieved excellent value for money invested. The funds spent is a small fraction of an average Horizon2020 project yet the achievement, in terms of scientific and engineering discoveries, intra-European integration and international cooperation. I can only applaud to activity and agility of the action's coordinators.

Action Rapporteur details and procedures

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In completing the Assessment Report the Action Rapporteur reviewed the following documents:

1. Action MoU (insert hyperlink)
2. Draft Action Achievement Report
3. Materials and website of workshops and meeting organized
4. Contents of Summer School teaching
5. Selected audit of publications

used the following methodology: standard evaluations approaches.

Please remember to write a summary assessment of progress on the first page of this report. This summary will be made public, while the rest of this report will not.





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Annex 1

Definitions:

COST Action Challenge (main aim)	“The research question addressed by the COST Action targeting scientific, technological, and / or socioeconomic problems”
COST Action Innovation	“The creation and / or development of new or improved concepts, products, processes, services, and / or technologies that are made available to markets, governments and society”
COST Action objectives	“COST Action objectives are the results that an Action needs to achieve in order to respond to meet its challenge. These are SMART (Specific, Measurable, Achievable, Relevant, Timely) and twofold: research coordination objectives and capacity building objectives.”
COST Action research coordination objectives	“Achieving these objectives turns COST Actions from initially scattered teams into one transnational team and leverages the existing funded research. These objectives entail the distribution of tasks, sharing of knowledge and know-how, and the creation of synergies among Action participants to achieve specific outputs.”
COST Action capacity building objectives	“Achieving these objectives entail building critical mass to drive scientific progress, thereby strengthening the European Research Area. They can be achieved by the delivery of specific outputs and / or through network features or types and levels of participation.”
COST Action networking activities	“any activities organised by the COST Action (whether or not directly funded by COST) in order to achieve research coordination and capacity building objectives.”
COST Action networking tools	“instruments through which eligible activities can be funded”
COST Action outputs	“direct results from the COST Action activities. These can be codified knowledge, tacit knowledge, technology, and societal applications.”
COST Action impact	“the short- to long-term scientific, technological, and / or socioeconomic changes produced by a COST Action, directly or indirectly, intended or unintended.”
COST Action deliverable	“a distinct, expected and tangible output of the Action, meaningful in terms of the Action’s overall objectives such as a report, a document, a technical diagram, a software etc. Action deliverables are used to measure its progress and success.”
COST Action milestones	“Control points in the Action that help to chart progress. They are also needed at intermediary points so that, if problems have arisen, corrective measures can be taken. A milestone may be a critical decision point in the Action where, for example, the MC must decide which of several technologies to adopt for further development (e.g. core group and MC meetings, mid-term reviews)”
Inclusiveness Target Country (ITC):	Current COST Member Countries targeted by the COST inclusiveness Policy (“Inclusiveness Target Countries” (ITC)): EU 13 (Bulgaria, Cyprus, Czech Republic, Estonia, Croatia, Hungary, Lithuania, Latvia, Malta, Poland, Romania, Slovenia, Slovakia), EU candidate countries (the former Yugoslav Republic of Macedonia, Montenegro, Republic of Serbia, Turkey) and potential EU candidate countries (Bosnia and Herzegovina). In addition, to comply with the EC criteria for ‘Spreading Excellence and Widening Participation’, Portugal and Luxemburg are included.