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Keywords: Roadmap

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[1] Public

[2] Restricted to other program participants

[3] Restricted to a group specified by the consortium

[4] Confidential, only for members of the consortium

1   Introduction

Brain-computer interfaces (BCIs) have become a popular topic for research in recent years. A BCI is a communication device which allows people to control applications through direct measures of their brain activity. A BNCI (brain/neuronal computer interaction) system extends a BCI by including other physiological measures such as muscle or eye movement signals. The number of BCI research groups around the world, peer-reviewed journal articles, conference abstracts, and attendance at relevant conferences are indicators of the rapid growth of this field. With dozens of companies and research groups actively participating in the development of BCIs and related technologies, collaboration, a common terminology, and a clear roadmap have become important topics.

To provide a solution to these issues, the European Commission funded the coordination action Future BNCI in 2010/2011. This project was the first effort to foster collaboration and communication among key stakeholders. BNCI Horizon 2020 aims to continue and improve upon the efforts initiated by Future BNCI.

A main result of BNCI Horizon 2020 is a roadmap for the BCI field. A clear and comprehensive roadmap produced by BNCI Horizon 2020 will lay the foundations for, and impact on, a (continued) dominance and clear visibility of European research groups in the future and will support the European Commission in their funding decisions for the new framework program Horizon 2020.

This document summarizes the final version of the roadmap document of BNCI Horizon 2020 (due by the end of M18). The roadmap contains compact information derived from material which was developed in the four work packages WP2, WP3, WP4, and WP5. Compared to the first public draft of the roadmap (M12) a shorter, streamlined and easy-to-read version was created by incorporating feedback by our consortium and our advisory board.

The main objective of the roadmap is to provide a global perspective on the BCI field now and in the future to the reader. For readers not familiar with BCIs, the roadmap introduces basic terminology and concepts. Furthermore the roadmap discusses what BCIs are, what BCIs can do, and who can benefit from BCIs. To support the main messages arguments are illustrated with use cases. After reading the roadmap, the reader will have a clear picture of the potential benefits and challenges of BCIs, the steps necessary to bridge the gap between current and future applications, and the potential impact of BCIs on the society within the next decade and beyond.

To provide more detailed information for the interested reader appendices for **Research**, **Industry**, **End user**, **Use cases** and **BCI Society** complement the roadmap.

All these documents, as well as the final version of the roadmap, are online available at the roadmap section (http://bnci-horizon-2020.eu/roadmap) of the BNCI Horizon 2020 website. The final versions of all these documents can also be found in the appendix of the current document.

2   Organization of the roadmap

The final version of the roadmap is organized as follows:

2.1   Who should read this roadmap?

This section gives a brief overview for whom (i.e. policy maker, investor, executive, innovator, technologist, or researcher), and to what purpose this roadmap was created.

Summarized, the roadmap will give an overview of the current status of BCI technology and potential future directions, and links to more detailed background information on the project website. Nevertheless the roadmap is also designed to provide basic information to reader which are interested in BCIs and wish to learn more about the topic and future applications.

2.2   Aim & 2.3   Executive summary

The sections explain the main objective of the BNCI Horizon 2020 roadmap.

2.4   What is a BCI?

What is a BCI? What does BNCI mean? What are possible applications for BCIs? In this section of the roadmap, we address these questions and provide basic background information on brain-computer interfaces.

2.5   Vision for 2025

This section is dedicated to the following points: Why are BCI important? Which impact BCIs will have? What is the focus for the future?

2.6   Use case scenarios

There are often a lot of misunderstandings about what BCIs can and cannot do. To provide a detailed explanation the roadmap explains in five scenarios what a BCI can be used for. In more detail

- BCIs can replace natural CNS output that has been lost as a result of injury or disease. Examples include communication (through a spelling system and voice synthesis) and motorized wheelchair control.

Depicted by the use case scenario: **Unlocking the locked-in**

- BCIs can restore lost natural CNS output. Examples include functional electrical stimulation of muscles in a paralyzed person and stimulation of peripheral nerves to restore bladder function.

Use case scenario: **BCI-controlled neuroprosthesis**

- BCIs can enhance natural CNS output. Examples include monitoring brain activity during prolonged demanding tasks such as driving a car and detecting lapses of attention, which alerts the person and restores attention.

Use case scenario: **Hybrid BCI-driven FES for stroke rehabilitation**

- BCIs can improve natural CNS output. Examples include using a BCI in stroke rehabilitation that detects and enhances signals from a damaged cortical area and stimulate arm muscles or an orthosis to improve arm movements.

Use case scenario: **NeuroTutor**

- BCIs can be used as a research tool to investigate CNS functions in clinical and non-clinical research studies.

Use case scenario: **Research tool for cognitive neuroscience**

For each of these use cases recommendation for the future are provided. More detailed information on the above mentioned use case scenarios (e.g. Users' Opinion, Ethical issues, Social aspects and long term risks and requirements) are provided in Appendix D. The appendix also contains the following additional uses cases:

BCI-controlled robot assistant, bionic hand with sensory feedback, cochlear implant adjustment, spinal cord stimulation for reach and grasp, seizure detection and suppression in epilepsy, cognitive stimulator, enhanced user experience in computer games, automatic emergency calls, medical examinations, adaptive neurofeedback training app.

2.7   Horizon 2020 and the place for BCIs

In Horizon 2020, funding is based on three pillars: excellent science, industrial leadership, and societal challenges. In this section the future of BCIs is depicted in the context of these three pillars.

2.8   BCI market and stakeholders

This section contains information about the BCI market and stakeholders. It presents a summary of the state-of-the-art of BCI sectors, BCI-related industry stakeholders, and key BCI applications in synergy fields. Additional information are provided in appendix B.

2.9   Ethics

This section deals with ethical aspects of BCI research (Task 4.3). Many ethical issues overlap with those in other domains (e.g. Internet & Privacy), but some are unique and are presented in a brief summary. Detailed information on these points are given in appendix C.

2.10 General recommendations

In this section the following key aspects are briefly summarized:

- Significant technological advances in BCI solutions.
- Active engagement of BCI experts in commercial applications.
- Development of implantable BCI solutions.
- Solid understanding of the psychological, neuronal, and functional changes induced by BCIs.
- Engagement of all stakeholders with the ambition to provide BCI systems for all societal and medical applications.

2.11 Appendix

Five appendices support the roadmap text:

Appendix A (Research)

Four sources of information were used to generate Appendix A: knowledge from the Hallstatt Retreat, the Future BNCI report, the BNCI Horizon2020 literature database 2011-2014 and the researchers' questionnaire. Each of these sources is detailed in section A.1.
Section A.2 is a summary of the current state-of-the-art on BCI concepts and paradigms, BCI data processing and BCI hardware and recording techniques. Both invasive and non-invasive approaches are considered. It is an updated, extended and re-organized version of sections 1-4 of the Research State of the Art described in D2.2.
Section A.3 is the finalized report of the researchers' questionnaire, which aimed to obtain the opinion of BCI researchers about the future of their field. After D2.2 was finalized, the questionnaire was re-sent to the researchers that did not respond in the first round, and the additional responses obtained are included in the final appendix.

Appendix B (Industry)

This appendix summarizes the industry contribution to the BNCI Horizon 2020 roadmap based on WP3 issues and related deliverables D3.1, D3.2 and D3.3. Section 2 describes all the sources used during the project including identified success stories from previous EU-funded projects that derived into BCI market products or prototypes classified into the different BCI application scenarios i.e. replace, restore, improve, enhance, and research. Section 3 presents a summary of the state-of-the-art of the BCI sector, BCI-related industry stakeholders, and key BCI applications in synergy fields. Section 3 also emphasizes BCI industrial interrelationships in several synergy fields and identifies related BCI products already in the market today. Section 4 portrays a future outlook of the BCI industry by assessing further market opportunities and by estimating the market impact of identified key BCI applications. Further, the future outlook in section 4 introduces practical guidelines and actionable recommendations derived from conclusive analyses of the selected use cases in the different BCI applications scenarios. Section 5 is based on original Research State of the Art of D2.2.

The main goal of this appendix is to present functional means, mainly for SMEs and policy makers, to support and promote BCI industry innovation, and to encourage BCI transfer and exploitation.

Appendix C (End users)

This appendix explains the key concept of the user centered design (UCD) process (Section 1). To define the state of the art (SoA) of UCD in the BCI field a comprehensive review of literature and a summarization of the main results of previous research projects that have dealt with ethical issues about BCI technology and more generally neurotechnology is presented (Section 2). In Section 3 a future outlook for an evaluation framework, an ethical guideline is presented. These sections are mainly based on Task 4.1, 4.2 and 4.3 of WP4 (details see D.4.5). Finally the recommendations for the development of BCI specific guidelines and regulations for BCI use in medical, commercial and legal context; specifications to BCI use in terms of sharing data and privacy against the background of general EU and US privacy regulations; and to debunk myths about BCIs by obtaining and presenting facts, and promote dissemination of such information to media and society, are given.

Appendix D (Use Cases and Focus Groups)

This appendix contains extended information on the use case scenarios (e.g. Users' Opinion, Ethical issues, Social aspects and long term risks and requirements) presented in the roadmap. The appendix also contains additional uses cases for the different application scenarios. The appendix is based on the main results of Task 4.3 of WP 4 (details see D4.5), which include a critical review of the literature and previous experiences (projects), whose results were incorporated into the use cases presented in section 1. Furthermore a consultation of end users, by means of Focus Groups and structured interviews (Task 4.2), was carried out. Related details (structured according the different scenarios) are presented in section 2.

BCI Society

This part describes the current status of a BCI Society. The BCI Society was officially founded on March 13, 2015. The launch of the Society is announced in the BNCI Horizon 2020 roadmap appendix which is linked with the project webpage (http://bnci-horizon-2020.eu/community/bci-society).

The BCI Society includes scientists, engineers, clinicians, and other interested individuals from around the world. The society's primary goal is to foster research leading to technologies that enable people to interact with the world through brain signals. It is legally based in Utrecht, The Netherlands, but operates internationally. The BCI Society aims to attract people from multiple disciplines who work with different approaches (non-invasive, implants, induction of sensory feedback, functional electrical stimulation, stroke rehabilitation, and so on), and with different end users in mind (gaming, enhancing, occupational, health monitoring, etc.). The society board aims to encourage other (emerging) BCI organizations to collaborate and join forces in organizing meetings where possible. In line with the BNCI Horizon 2020 roadmap, the society aims to include all fields relevant to the BCI concept, including research, users, and industry.

2.12 Consortium

This part of the roadmap presents all partners and provides the contact details. In the electronic version of the roadmap Hyperlinks to the websites of the institutions are included.

3   Appendix

This appendix consists of 6 files: the roadmap main document and the five appendices:

- Roadmap_BNCI_Horizon_2020.pdf
- Appendix_A_Research.pdf
- Appendix_B_Industry.pdf
- Appendix_C_End_User.pdf
- Appendix_D_Use_Cases_Focus_Groups.pdf
- Appendix_E_BCI_Society.pdf