Ambient Intelligence Based Vision to At-Home Laboratory for Personalized Monitoring and Assessment of Motion-Cognitive State in Elderly

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***Abstract*—Humans loose functionality of many physiological systems and, hence, the social adaptation, after the age of 60..65 years. The motor, cognitive, and circulation systems are the most essential for personal social adaptation. The human brain adapts to these age-related dysfunctions by means of natural reorganization and modification of its activity, though non-sufficiently. In this paper we review possible "external" interventions based on the Ambient Intelligence (AmI) technology. Interventions aim at compensation for growing social de-adaptation of the elderly that takes place due to cognitive and motor impairments. We propose and discuss a novel concept of AmI-based "supplementary neocortex" (neo-neocortex) or "augmented intelligence" that in a close-to-natural form would partly substitute declining own cognition and mobility. We introduce our design vision of At-Home Laboratory (AHL) assisting the elder person posted on the real state of his/her functionality in everyday life.**

I. Introduction

Humans loose functionality of many physiological systems and, hence, the social adaptation, after the age of 60..65 years [1]. The motor, cognitive and circulation systems are the most essential for personal social adaptation. The human brain adapts to these age-related dysfunctions by means of natural reorganization and modification of its activity, though non-sufficiently [2]. In this paper, we consider "external" interventions to compensate for growing social de-adaptation of the elderly that takes place due to cognitive and motor impairments. Possible intervention can apply the Artificial Intelligence (AI) methods and the Ambient Intelligence (AmI) technology [3], [4], in particular.

This paper stresses the attention on the social adaptation as one of the major problems in elderly [1]. We review existing research on natural and "external" strategies to keep the cognitive and motor functionality over the required level. The review results in specific requirements to AI solutions, and we analyze the requirements in the sphere of social adaptation and current sensor-based monitoring methods and technologies to measure the cognitive and motor functionality.

To realize these requirements we propose and discuss a novel concept of At-Home Laboratory (AHL). It acts as AmI-based "supplementary neocortex" (neo-neocortex) or "augmented intelligence" that in a close-to-natural form would partly substitute declining own cognition and mobility. The concept provides a kind of artificial cerebral neocortex based on AmI to mimic the activity and functionality of real brain/cortex. Our design vision of AHL is based on the solutions proposed in our previous work [5], [4], [6], [7], [8], [9]. These solutions support the expectation that AHL can provide effective digital assistance of the elder person posted on the real state of his/her functionality in everyday life.

The rest of the paper is organized as follows. Section II considers the problem of social adaptation in elderly and reviews existing approaches where AI solutions are used for assessment of the motion-cognitive state. Section III proposes the AHL concept for regular monitoring and assessment of human wellness and motion-cognitive functions in everyday life. Section IV introduces our AmI-based vision for implementing the AHL concept on the recent development level of neurophysiological methods as well as of information and communication technology. Section V concludes the paper.

II. Social adaptation in elderly

Social adaptation is acknowledged as one of notable societal problems of modern global society, and in ageing population in particular. Let us review in this section some existing approaches where AI solutions are used in assessment of the human motion-cognitive state.

A. The Risk of Social De-Adaptation in Elderly

The social adaptation is a composite concept which includes varied measures of human's physical and mental capabilities, such as personal security, self-service, possibility to communicate with surrounding and remote people, and free mobility. Correspondingly, loosing or diminishing of these capabilities would directly lead to growing social de-adaptation and, thus, to decreased quality of life, in particular the elderly everyday life.

Ageing humans are the most vulnerable to the risk of the social de-adaptation because starting from the age of 50 years the performance and functionality of certain human physiological systems gradually decline and become evident by the age of 60..65 years [1]. For example, the elder people have continuously decreased muscle mass, they move slower, their muscle force, power and coordination are diminished [10], [11]. Correspondingly, there is a growing gap between the declining functionality and its required level along the life span (as Fig. 1 schematically shows).

Some basic cognitive abilities such as speed of information processing, memory, calculation, understanding, reaction on

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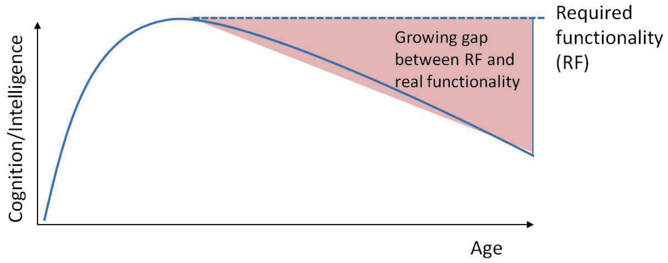

Fig. 1. Growing gap between ever decreased cognitive/intellectual functionality (blue curve) and its required (dashed line) value over the life span

stimuli, decision making are notably deteriorated in older adults [2]. Alike the motor, these cognitive age-related functional modifications lead to the risk of loneliness, abandonment, non-inclusiveness, and, hence, diminished quality of life under older age. Ultimately, many of older people found themselves in highly unfriendly new environment.

The modern world presents ever growing requirements to human brain that can interfere the social adaptation, among which are the following.

1) Ongoing “digital revolution” that demands to actively use Information-Communication Technologies (ICT) that inevitably and profoundly transforms human thoughts and behavior [12].
2) Global ageing of population, as was reported, e.g., in [13].
3) Expansion of some age-associated diseases, such as arterial hypertension, neurodegenerative diseases, e.g., Parkinson’s disease (PD) and Alzheimer’s disease through the global population.

Some core physiological functions, such as motion (motility/mobility), cognition/intelligence, and circulation, appear critical to provide personal self-service and security. Correspondingly, deficits of human intelligence and ability to freely move in the future decades would only have increased. Therefore, to keep personal social adaptation controlled it is essential to provide required functionality of the motor system, cognition and circulation over acceptable functional threshold, because these systems/functions jointly provide decision-making, understanding and inclusiveness, self-service, locomotion that actually build-up the social adaptation. In a way, the brain appears as focus of these three kinds of functionality because normal cerebral circulation allows both reliable motion and cognition, especially under ageing.

To better understand the problem of social adaptation, one must consider that within human ageing there are periods of

1) unaltered functionality,
2) lowered functionality,
3) the period of translation of the latter to disease.

That allowed inventing the concept of so-called “rectangularization” of functions along ageing that stands for maximal prolongation of a function on the normal (required) level, unless dying [14]. As the mankind eventually reaches its maximal longevity [15], the condition of ageing would become much more familiar and usual to people. It is expected that more people will work in their late age, and the economy will produce more goods for the elderly customers. That is known as the Silver Economy Phenomenon. Additionally, many of the aged and experienced people due to deficit of qualified specialists would stay employed as long as possible. That demands keeping their physical and mental performance on relatively high (required for work) level.

In addition to ageing, many people suffer of various age-related diseases. For instance [16], more than 9% of global population suffers of the cognitive deficits, 2% of older people suffer of PD [17], and mere 30% of adults have elevated arterial blood pressure. As a result, some of ageing humans face the necessity to keep working along being ill. Economical burden for social adaptation of ageing population imposed on the society appears as hectic. For example, PD lowers the quality of patient’s life, and financially exhausts the family and state [18]. Therefore, rehabilitation and, hence, social re-adaptation of older people, patients with neurological disorders or people with arterial hypertension may lead to clearly visible positive financial effect on the state scale.

B. “Natural” Neurophysiological and Behavioral Solutions to Social Adaptation in Elderly

There are at least two optimistic solutions to cope with growing social de-adaptation that can be marked as the “natural” ones. First, the human brain proved highly adaptive to the age-related neurodegenerative changes. According to the scaffolding theory of aging and cognition (STAC) the human brain is capable of reorganizing its connectivity, and of repairing its impairments so that the cognitive functionality is kept long on a reliable level [2]. Indeed, while capacity of varied kinds of memory and data processing speed gradually declined, the vocabulary and world knowledge grows along the age [2]. It is also essential that “scaffolding” of the cognitive functionality can be promoted by training and cognitive activity [2]. Therefore, the brain itself can effectively cope with growing cognitive deficit by the neurophysiological means.

Second, tremendous assistance to ageing man can be provided by his/her family (actually by a kind of “supplementary brain”). It is actuated in the concept of “Ageing Together” (in a family or couple) [19]. Ageing together leads to a notably lesser social de-adaptation due to a phenomenon known as “joint cognition” and task-sharing [19]. This strategy can be regarded as a kind of adaptive behavior both from the side of a subject and his/her companion.

Many other existing solutions for social de-adaptation are centered around sophistication of the social work with the disabled elder people.

All in all, family and social services are critical to control functionality of physiological system of a person. In a way, they provide a kind of “augmented functionality” around an elder person or patient. Still, some elder people are not motivated enough to train their cognitive capabilities under ageing, or do not have opportunity to share tasks. As such, they become more dependent on the quality of the local social service. Therefore, an “external” system—independent of the user—would be helpful for the purpose of social adaptation in elderly.

C. "External" Scaffolding of Cognitive Activity

Unlike to the digital technologies, which eventually become ever more sophisticated, the human brain develops over the lifetime and passes through definite ontogeny stages:

1) development (growing),
2) optimal functionality at adulthood,
3) ageing characterized by decrementing motor, cognitive, and intellectual functions.

Therefore, technological solutions for cognitive applications are advancing all the time and can well serve as rehabilitation tools. Yet, even such accustomed at-hand technologies as Internet or smartphones allow delegating certain human intelligence functions to such digital "extends" of mind as Google, Wikipedia, and social networks. These semi-structured sources of knowledge are well accessible and understandable to aged or disabled people, so they can operate as the "external" analogs or supplements for the internal scaffolding (according to the STAC theory). Nonetheless, these "extends" require active volitional efforts from the ageing people that is not the case for many of them. Therefore, a proactive scaffolding system would be more appropriate.

D. AI-Based External Scaffolds

The AI methods could serve as an external support of declining cognitive performance is to implement [20], [21] which seems to be the most perspective scaffold due to its similarity and, hence, better compatibility to the natural human intelligence [22]. Therefore, AI provides a kind of "augmented functionality (intelligence)" to compensate for progression of physical, cognition and intelligence disability in aged, and, more specifically, in chronically ill aged humans. Growing AI around the user would proportionally compensated for decreasing functionalities and thus help a human "comfortable arriving" to older age and comfortable living being older, as Fig. 2 schematically shows.

Ongoing "digital revolution" provides ever advancing opportunities to invent novel channels of communication between a human and his/her societal surrounding, and novel programs of personal monitoring of human functioning. From the other hand, the older generation experiences difficulties to make use of these new opportunities. The AI methods seem to be

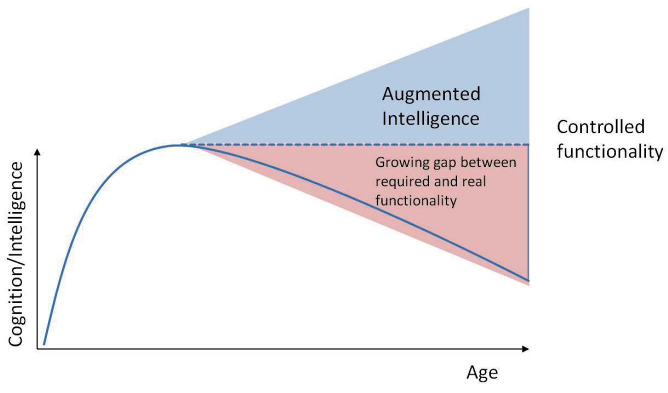

Fig. 2. Concept of compensatory action of "augmented intelligence" for decreasing cognitive/intelligence functionality

the best to provide communication with the world and to control the state of health in the elderly by sharing cognitive and intelligence functions. Invention of AI systems would have provided notable economical effect because in remote territories by delegating the user an ability to control his health status without being visited by physician or going to clinics.

Such technologies as Internet of Health Things (IoHT), smart environments (SmE), assistive activity living (AAL), and pervasive computations allow creating AI systems that are capable of monitoring, assessing, reminding, advising, warning for personalized convoy of a user. The AmI methods seem to be the best AI platform to invent methods for sustained social adaptation in the elderly [3], [23]. Presented modern systems of AmI substantially augment activity of either formal (physicians, social workers) and informal (family) assistants of patients. Development of such AmI technologies would accelerate smart Internet technologies in the domain of cyber medicine, and by that to restore the quality of life and social adaptation of ageing humans.

To conclude this review, the major idea of our study is to discuss the problem and possible approaches to gentle compensation of declining cognitive, motor, and circulatory functionality by means of AmI. The next section considers how AmI can be used within our AHL concept for regular monitoring and assessment of human wellness and motion-cognitive functions in everyday life

III. At-Home Laboratory (AHL)

Our previous work [5], [4], [6], [7], [8], [9] on mobile healthcare and cybermedicine systems provides basic solutions to support the AmI-based vision to AHL for personalized monitoring and assessment. In this section, we analyze the requirements to AI solutions for the case of everyday monitoring and assessment of motion-cognitive state in elderly

A. Current Requirements to AI Monitoring Systems of Human Wellness and Functions

To keep the older and/or disabled people within zone of social adaptation, the AI applications must be capable of: 1) monitoring, 2) assessment, and 3) management of cognitive, motor, and cardiovascular status of a human. In the study of Huh et al. [24] the following requirements for wellness self-monitoring important for older people and their families were revealed: 1) minimal data complexity, 2) manipulability, and 3) transparency. Additionally, following factors were found to increase the desirability of such systems: 1) convenient access to their health and health information, 2) a simple, accessible interface, 3) and support for memory issues [25].

The ultimate goal of AI in healthcare appears as to be a system of transparent, accurate and comfortable in use services that could automatically test functionality of physiological systems of the human organism. Such system was yet actuated in the concepts of Consumer-Health Informatics [26] and Smart Home [27], [28]. In future, that would provide the customer to participate in evaluation of his health status (self-quantification) and even decision-making.

AmI has further distinct characteristics that are specifically required for healthcare service-oriented applications [29], [6].

1) context aware (here-and-now situation),
2) personalized (customized and adaptive to the user),
3) anticipatory (predicting user's needs),
4) adaptive (modifiable for user's habits),
5) ubiquitous (embedded among the environment),
6) transparent (acting without direct action or knowledge by the user).

The enlisted characteristics well match those of the "natural" intelligence. The most fascinating and challenging issue in this list, to our opinion, is the AmI adaptability. The ability of AmI-based healthcare system would allow proportional compensating the declining capability of own user's intelligence (Fig. 2).

Two major aspects can be outlined for studies of AI/AmI methods applied to human motion and cognitive status of elder and disabled humans. The one is to elaborate (or choose among existing methods) actual diagnostic procedures, tests and sensors ready to be embedded in the system of automated diagnostics. The other aspect appears as development of system architecture and AI methods to monitor and assess functions of a human for further intervention in his/her life by means of recommendations and reminding.

B. Methods and Tests for Assessment of Human Motor Function

As for the motor function, there are two modern methods which are regarded as the "gold standard" in that domain: 1) the video motion capture, 2) walkway force platforms [27]. These methods are precise, reliable, but costly and complex, and they are used exclusively in laboratory settings. Therefore video motion capture and instrumented walkways are poorly suited for the purposes of AmI. Through the last several years, the technologies of gait assessment based on wearable inertial sensors, e.g., accelerometers, gyroscopes, "smart shoes", have advanced [30], [31], [32], [33], [34], [35], [36]. These wearable accelerometers and gyroscopes in a form of Inertial Measurement Units (IMU) of smartphones allow reliably recording of gait characteristics [34]. Additionally, life space assessment and human's mobility patterns evaluated with help of GPS technologies are used for assessment of activity [37], [38]. This allows to judge on motion and even cognitive function by means of space of human's travels.

A widely-used and informative experimental paradigm that easily allows assessing motion function is the TUG (timed Up and Go) test, which appears as a chain of events: seat-to-stand, stand-to walk, walk (3 m), U-turn, back walk, and stand-to-seat. This test ideally mimics daily living activity of a man. Currently this test is widely used in studies of PD and other motor disorders, including freezing of gait [39], [40], [41].

C. Methods and Tests for Monitoring of Human Motion-Cognitive State

Among the most easy-to-do psychophysiological methods to measure cognitive functions are the simple (SRT) and the choice reaction time (CRT). The SRT measures time between visual (or audio) stimulus and the motor respond to it (by as rapid as possible pressing a button on keyboard) [42]. The CRT holds for the time required to discriminate between 2 different stimuli, e.g. between green and red light [43]. SRT and CRT are believed to be linked to specific neural mechanisms, correspondingly, to the motor pre-programming, and to functions of attention, decision making and perception of stimuli.

Digitomotography can also be used to measure the motor function, for example, to assess bradykinesia in PD patients [44]. This method appears as index finger tapping that can be easily performed both using a mechanical tapper and a smartphone tapping application [45]. Additionally, a tablet-based application that combines finger tapping test and reaction time test was proposed [46]. The finger tapping has proved as a good clinimetric test which reliably predicts some specific characteristics of surface electromyogram and accelerometry in PD patients [47].

The motor TUG test (single task test) can be combined with mental task in a form of dual task TUG (DT-TUG), when a subject has perform the TUG test while recalling backward digits (e.g., to subtract number "1" or "3" from number "100" [48], [49]. Therefore, this test, alike the CRT, allows combined assessment of the motor and cognitive functionality. All above listed methods are ever increasingly installed in mobile nets and, correspondingly, can be installed in AmI. In particular, wearable sensors (in clothes, shoes) are yet practically embedded in the IoHT systems [50], [51].

D. At-Home Assessment of Human Wellness and Motion-Cognitive State

Modern methods of AmI are mostly based on rather complicated in use, time consuming, and costly systems of wearable sensors, which are usually used in the laboratory or clinic setting. Also, the laboratory settings usually exert strong inference of familiarization to its conditions and demand strict following to standard study protocols. All these issues prevent reliable description and/or diagnostics of human functions in laboratory conditions. As much as 87% of examinations for assessment of PD occurred in a clinic or lab [52]. As such, we regard that surveillance of human functional parameters (motion, cognition, circulation) must be 1) transparent, 2) "natural", 3) continuous, and 4) available by its cost. Therefore, our approach to the problem of social adaptation in the elderly and chronically ill humans is based on implementation of intellectual systems of sensors and other sources of information to at-home, though equivalent to the laboratory, setting.

To embody that, we consider assembling an available everyday mobile devices (e.g., smartphone, tablet, surveillance camera) and mobile apps in an intellectual system which is capable of such operations as 1) surveillance (acquisition of information), 2) assessment of information (instant diagnostics), and 3) issuing recommendations (corrective decisions) for the user, his family and involved specialists (physician, social worker). Current motor performance, cognitive status, and circulation functions based, consequently, on the video motion capture, reaction time tests, heart rate variability and blood pressure monitoring could serve as sources of information on the functional status of a subject.

All in all, we propose to implement a principally novel type of data collection, based on the use of intellectually assembled mobile devices and apps to conduct laboratory tests in at-home setting. We also plan to compare validity and reliability of the data gained by such intellectual at-home system with conventional diagnostic systems operating in laboratory setting. As such, the project is aimed at creating and clinical evaluation of a prototype of at-home laboratory (AHL), which being based on AmI would have operated as a kind of "augmented intelligence" [9].

Having in the mind the heterogeneous character of the collected signals, especially their non-structural and semi-structural nature, acquisition and assessment of data obtained looks as a non-trivial basic problem. Therefore, to invent such "augmented intelligence" must be targeted on development of methods, models and algorithms of AI (AmI) system based on mobile devices and apps. Additionally, the project has a practical value since the AHL concept would have served as a novel physiological tool capable of collecting data deprived of "laboratory interference".

IV. Neurophysiological and Technological Vision on AmI-based AHL

In ideal, the AmI environment and the AHL built on its platform can be imagined as a kind of transparent, adaptive, personalized, and anticipatory [29] supplementary artificial cortex which is thought to scaffold decreasing motor, cognitive and other capabilities of the ageing or gradually disabling man. This imagination is schematically depicted in Fig. 3. The new cortex is thought as system of sensors, either implanted, wearable (accelerometers, gyroscopes) or external (video) and the Internet applications that acquire, analyze the data, and produce semantic content that can be used in a transparent, adaptive and personalized way.

From the software architecture point of view, the AHL is depicted in Fig. 4. Our technological vision is based on the smart spaces technology for Internet of Things (IoT) environments. The related solutions are proposed in development of mobile healthcare systems and at-home labs [5], [4], [6], [7], [8], [9]. The user (patient) is in the middle. Various sensor devices (wearable, implantable, etc.) as well as local and remote services are used as data sources, forming a complex data processing system. The sensed data are processed and cooperatively analyzed by software agents, which are running

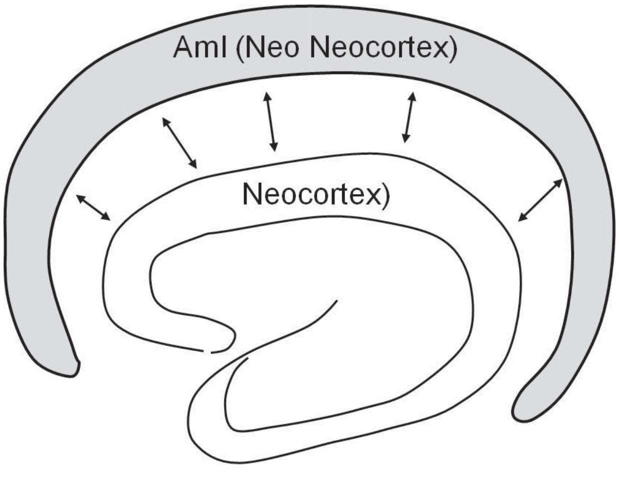

Fig. 3. Neurophysiological vision of neo-neocortex in form of AmI-based augmented intelligence

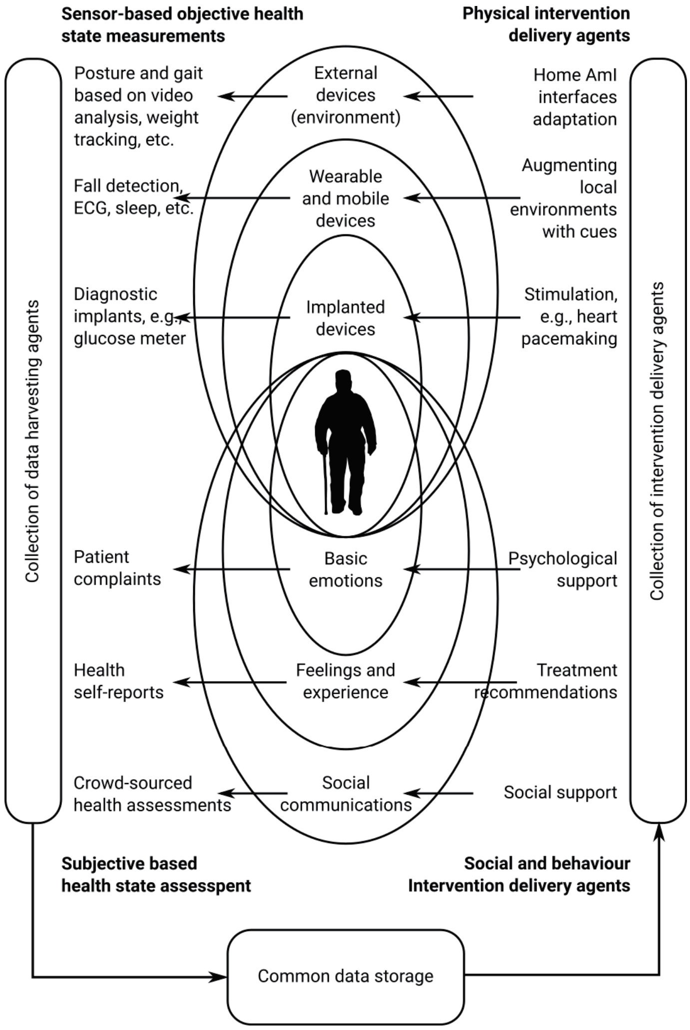

Fig. 4. Technological vision on AmI-based AHL

either in clouds or on devices in local IoT environment. This approach follows the Edge-centric and Fog computing. The aim is at involving all appropriate resources to the computation, even small surrounding devices.

The use of various well-known and/or specialized technologies is possible to implement the requirements to AI solutions in AHL. The applicable technologies for AmI-based systems are summarized in Table I. Their combination allows to perform distributed computing and to follow the Edge-centric and Fog computing, for involving different devices into the computation. The computation in AmI-based systems needs consideration of the following conditions.

1) The distribution, mobility and resource limitations of the participants in the calculation.
2) The heterogeneity, volumes, and dynamics of data involved in processing.
3) Incomplete knowledge of the individual participant about the whole system.
4) System performance scalability by the number of participants and volumes of data.

Therefore, the involvement of available and appropriate devices makes it possible to expand the capabilities of human

TABLE I. AmI TECHNOLOGIES

Task	Technologies
surveillance (acquisition of information)	Data transfer: cable, IoT (ZigBee, Bluetooth, WiFi, LTE, RFID), GPS; data storage: ontology (RDF, OWL), relational database
Assessment of information (instant diagnostics)	Statistical, spectral, cluster, semantic, probabilistic, fuzzy, dynamic analysis
Issuing recommendations (corrective decisions)	Syntactic, ranking algorithms
Infrastructure organization	Semantic web (SmartM3, OpenIoT, SOFIA2)

adaptation. These considered technologies allow the newly joined device to participate in computation (taking a part of it). The result is even resources distribution. Certain processing is performed near the data collection point, i.e., near the person in her/his everyday environment.

V. Conclusion

The key hypothesis of this paper holds that methods of AmI can be actuated by means of routine customary available mobile devices such as smartphones, tablets, sensor screens, surveillance camera, and at-hand medical sensors. Such devices are for everyday life, and they can be installed at home and other out-laboratory and out-clinic setting in the form of a mobile smart Internet-based system. The latter is capable for detecting specific abnormal signatures and patterns of 1) the motor function, 2) cognitive functions, 3) circulation parameters and to compensate for them by means of monitoring, assessment, warning, informing on current state of a function, and corrective advising, with the opportunity for a physician or a third side (family) to take part in monitoring. As such, the AHL concept and its AmI-based vision are elaborated to take upon some functions of outpatient clinics and social service. We stress that AHL is about creation of a supplementary "artificial brain neocortex" or a "neo-neocortex", which could function as a kind of augmented intelligence for the elderly.

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