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Perspective

Information and communication technology solutions for outdoor navigation in dementia

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Abstract

Introduction: Information and communication technology (ICT) is potentially mature enough to empower outdoor and social activities in dementia. However, actual ICT-based devices have limited functionality and impact, mainly limited to safety. What is an ideal operational framework to enhance this field to support outdoor and social activities?

Methods: Review of literature and cross-disciplinary expert discussion.

Results: A situation-aware ICT requires a flexible fine-tuning by stakeholders of system usability and complexity of function, and of user safety and autonomy. It should operate by artificial intelligence/machine learning and should reflect harmonized stakeholder values, social context, and user residual cognitive functions. ICT services should be proposed at the prodromal stage of dementia and should be carefully validated within the life space of users in terms of quality of life, social activities, and costs.

Discussion: The operational framework has the potential to produce ICT and services with high clinical impact but requires substantial investment.

Keywords: Social participation; Intention recognition; Assistive technology; Mobility; Cognitive decline; Disorientation; Situation-aware assistance

1. Outdoor and social activities in dementia

1.1. The vicious loop of cognitive impairment and social isolation

With aging, the risk of dementia, especially Alzheimer's disease (AD), markedly increases (prevalence of >20% at age ≥80 years). Mild stages of AD dementia are characterized by cognitive deficits, some behavioral symptoms, and functional disabilities in the instrumental activities of daily living with progressive loss of autonomy [1]. Mild cognitive impairment (MCI) is a prodromal stage of dementia with manifest memory decline but preserved activities of daily living [2].

Social cognition and activities can have a major impact on the evolution of symptoms and the maintenance of quality of life along the course of dementia [3]. Social cognition in MCI and AD dementia often remains intact until later stages of the disease [4], although early behavioral changes, such as depression or apathy, may affect social interactions.

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However, social activities are most heavily affected by spatial disorientation, which increases the risk of getting lost and exhibiting wandering behavior (wandering behavior in the broader sense includes forms of confused walking behavior even if it originates from an initially purposeful behavior [https://www.alz.org/care/alzheimers-dementia-wandering.asp]) [5]. Consequently, patients reduce outdoor mobility leading to a more sedentary lifestyle and social isolation, with a primary worsening of the quality of life and with a secondary negative impact on cognitive functions, cardiovascular tone, brain plasticity, and mood. Therefore, support of social activities is a major theme for future clinical research as well as treatment and prevention of dementia.

1.2. Ideal information and communication technology solutions for user's outdoor mobility

Information and communication technology (ICT) solutions can support autonomous outdoor mobility empowering participation in social events of patients with mild dementia. Such functionality is supported by assistive technology devices (ATDs), typically in the form of wearable devices which contain hardware and software that create a location-based service using global positioning system (GPS), cellular, and other signals. Ideally, such devices should efficiently fulfill the following functions:

1. Acquire active or passive user's inputs (typically, the user will actively input his/her destination into the system. Alternatively, the system can learn typical routes from the user's daily behavior and infer the intended destination from the actual user behavior [passive input]) about routes and goals. The system should integrate these inputs into the individual context of the user, considering cognitive and physical resources, personal habits and preferences (for example, valuation of autonomy vs. safety), and environmental factors, such as social networks, and availability of socially salient places and events;
2. Acquire real-time information on the local conditions (for example, weather forecast, traffic, public transportation, and hours of social events);
3. Recognize route obstacles (for example, critical street conditions), user's psychophysiological stress, irregular locomotion or falls, and dynamic changes of the planned routes and goals of outdoor transitions;
4. In case of disorientation, provide step-wise guidance through a transition routine or suggestion of alternative routes and request of feedback on intended goals; in potentially dangerous situations, provide hierarchical alarms to predefined stakeholders.

Challenges for the fruitful use of ATDs supporting outdoor mobility in users are the harmonization of communication systems among different stakeholders, the shared information of these devices raising the issue of user's privacy, and the user's level of cognitive impairment and resources (see Table 1 for an overview). An ideal ATD for supporting outdoor social activities in mild dementia should detect and support user intentions and goals. It should flexibly and automatically adapt to changes of a user's plans and goals, interpreting deviations from typical behavior in the context of (1) actual extrinsic factors, such as traffic situation, opening hours, (2) actual intrinsic factors, such as the user's level of psychophysiological stress and residual perceptual, cognitive, motor, and coping abilities, and (3) long-term intrinsic factors, such as favorite pattern of transportation, and social activity routines. Furthermore, the ideal ATD should combine a high level of safety with a high valuation of user preferences for autonomy and privacy. These key features of an ATD can be represented in terms of a balance across at least three target dimensions:

1. System usability versus feasibility;
2. System reliability versus flexibility; and

Table 1
Cognitive and behavioral characteristics of people with mild dementia, support provided by assistive technology devices, and minimum user's requirements for the use of these devices for outdoor navigation

Mild dementia deficits	ATD support	Minimum user's requirements
Disorientation, wandering, and getting lost in unfamiliar environments [6]	Psychological support, encouragement, and navigation inputs for wayfinding [6]	Relatively preserved personality [6], interests, motivation [7], and drive; ability to understand a simple visual or auditory cue [8,9]. Requirements tested by standard clinical scales
Spatial memory, visuospatial processes, planning, decision making, directed attention, and processing of multiple tasks [10] during outdoor transitions	Prompts on routes and strategies by one sensory channel at a time and only the next goal (no sequence)	Relatively preserved abilities to use a step-wise support [11] by ICT-based ATDs. Requirement evaluated by an assessment test with the device
Abstract reasoning and planning [12] during problems to find the way	Concrete prompts directed to the next goal	Relatively preserved abilities to follow instructions formulated in simple concrete terms [11] by ICT-based ATDs. Requirement evaluated by an assessment test with the device
Operation on technical devices to ask for support in case of disorientation	Detection of barriers, stress conditions, and generation of automatic prompts	

Abbreviations: ATD, assistive technology devices; ICT, information and communication technology.

3. User safety and monitoring versus autonomy and privacy.

In the subsequent sections, we will deal with the emerging state of technological developments for ideal ATD solutions for outdoor activities in mild dementia. We integrate these developments into an operational framework exploiting features of usability, feasibility, flexibility, safety, and autonomy by a design process that reconciles the values and needs of people with mild dementia, relatives, and other stakeholders. Furthermore, dimensions for the evaluation of effectiveness of ATDs will be discussed. Finally, we will suggest how to integrate these solutions into a multimodal approach combining psychosocial support of patients and family caregivers.

The presented perspective reflects a cross-disciplinary consensus among co-authors from different disciplines (old age psychiatry, neurology, cognitive psychology, computer science, biomedical engineering, social sciences, and ethics). All authors contributed to the development of all sections and subsections from the point of view of their expertise. The review of the literature was limited to the core topics selected by the cross-disciplinary workgroup.

2. The emerging state of ATD support: Core concepts and features

2.1. Needs and values of stakeholders

Understanding the needs and values of key stakeholders such as users, caregivers, and service providers represents an important starting point for the development of ideal ATDs for supporting outdoor mobility and social activities in mild dementia. A related exercise is to define what the values to prioritize are and how these priorities differ among the stakeholders. Although literature in other fields addresses these issues, only two studies have addressed them in relation to dementia, privacy/autonomy versus surveillance/safety [13], and freedom/autonomy versus safety [14] (Table 2).

2.2. *Usability versus feasibility, reliability versus flexibility, and safety versus autonomy: From dichotomy to continuity*

Usability of ATDs for supporting outdoor navigation in people with dementia has mainly been studied in experimental settings [26]. In this setting, people with mild dementia could understand the visual and auditory cues of ATDs and interact with touch screen devices and mobile phones with an adapted user interface [27]. Data suggest that familiarity with a device determines its usability until more advanced stages of dementia [28]. Therefore, the implementation of an ATD functionality on a hardware that is familiar to the user and the ability of a system to adapt to the changing needs and capabilities of its user so that it can be used from very mild until advanced stages of dementia will determine the successful implementation of an ATD in everyday use.

Clinical experience suggests that under stress conditions, people with dementia tend to disregard ATD sensory cues. This emphasizes the importance that ATDs detect stress conditions and disorientation of their users early and provide active support and communication strategies that are able to overcome these constraints. However, highly flexible interventions require more complex systems, and so the reliability and feasibility of such devices is debatable when applied in the field of dementia. Novel technologies with high-end computing and more efficient algorithms may be able to reduce this friction between flexibility and reliability of an ideal ATD (see Section 2.3, in the following). They require, however, rigorous evaluation of effectiveness in real-world settings to justify their use and reasonably prevent any risk for users (see Section 3.2, in the following).

In perspective, an ideal ATD implements various coordinated strategies for the management of getting lost during a

Table 2
Values important to stakeholders for the development of ATDs (alphabetic order)

People with dementia	Caregivers (family and professional)	Service providers (staff and management)
Autonomy [13,15]	Consent [13]	**Alerting** [15]
Consent [13]	Dignity [13]	Autonomy [13,15]
Dignity [13]	**Interdependence** [13,15,20]	Consent [13]
Emergency help [15]	**Inclusion** [15]	**Costs** [13]
Freedom [13,16]	Mobility [20]	Distracting [15]
Human rights [17]	**Participation** [15]	**Feasibility** [13]
Independence [8,9,13,18–20]	**Patient-caregiver satisfaction** [21]	Mobility [20]
Privacy [8,9,13,17–19]	Quality of life [8,18,21]	Privacy [8,9,13,17–19]
Quality of life [8,18,21]	**Relief/respite** [15]	**Quality of patient care** [4,21,23–25]*
Respect [13]	Respect [13]	**Reminding** [15]
Safety [9,13,16,19]	Safety [9,13,16,19]	Respect [13]
Trust [13]	**Security** [9,15,19]	Safety [9,16,19]
Well-being [13,21,22]	Surveillance [9,13]	Surveillance [9,13]
	Well-being [13,21,22]	

Abbreviation: ATD, assistive technology devices.
NOTE. Values that are particular for any stakeholder are written in bold.
*Including quality of life, quality of care, and quality of life for families.

Table 3
An example for an adaptive ATD approach to intervention

Deviation from typical behavior occurs, and system…	Ensuing system reaction
• Infers intended deviation, detects no psychophysiological stress reaction, no evidence on increased risks.	≻ Waits, no immediate reaction.
• Infers unintended deviation, detects no psychophysiological stress reaction, no evidence on increased risks.	≻ Asks for a simple confirmation by user, and asks if support is needed.
• Infers unintended deviation, detects psychophysiological stress reaction, no evidence on increased risks.	≻ Asks for explanation by user and offers situation-adapted support.
• Infers unintended deviation, detects no evidence on increased risks, and has received appropriate feedback by user.	≻ Delivers step-wise guidance to correct the route.
• Infers unintended deviation, detects increased psychophysiological stress reaction, and receives no appropriate feedback by user.	≻ Provides hierarchical alarms to predefined stakeholders, such as caregivers, medical staff, or police.
• Detects possible risks (irrespective of the foregoing sequence of events).	≻ Provides hierarchical alarms to predefined stakeholders, such as caregivers, medical staff, or police.

Abbreviation: ATD, assistive technology devices.

transition or activity outside the home. An advanced flexible ATD discriminates whether the user intentionally or unintentionally deviates from a predefined target, possibly based on previous training on user's behaviors and physiological reactions (for example, heart frequency rate) to stress in similar situations. If an ATD is able to understand a user's current situation, intentions, and psychophysiological reactions, it may, for example, discriminate if the user changes the route voluntarily to greet an acquaintance on the other side of the road or due to wandering behavior. The ideal ATD should then adapt its reaction to the given situation (see Table 3 for an example). Similarly, the mode of input that may be required in instances when the system is uncertain as to the intentionality of some behavior of its user should be adapted to the user's preferences and remaining abilities. Thus, interpretation of voice input may be a future option to support operation of the system by a user with limited cognitive abilities that may have difficulties using more traditional modes such as key, mouse/track ball, or touch mechanisms. An ATD should offer a hierarchy of input modalities based on previous experience and current situation, considering user preference, remaining abilities, and environmental factors.

An ATD providing an adaptive response could be termed as situation-aware deliberative ATD (we here use the concept of "reactive" and "deliberative" agents as it is established in artificial intelligence (AI) research. Although reactive systems provide simple mappings from inputs (sensors) to outputs (assistance), deliberative systems maintain a more complex internal model of the context under consideration). Reliability of this flexible decision-making process is much more challenging when compared with a reactive, fixed response model in which ATDs send alarms to caregivers whenever users abandon preselected routes or safe areas. A reactive model of ATD intervention may be the most appropriate approach in some contexts such as when there is a risk of falls or accidents or with some patients characterized by psychophysical frailty, poor residual cognitive and motor functions, and low stress coping abilities. This suggests the importance of combining rather than dichotomizing the features of flexibility and reliability of ATDs in a context-dependent manner, as a function of the risks of the individual users' environment and their available cognitive and physical resources. Panel 1 provides an overview on system- and user-driven key factors of usability and feasibility of a situation-aware deliberative ATD.

Another challenge is the balance between safety and autonomy. Safety through surveillance potentially allows more opportunities for user autonomy during outdoor transitions. However, safety and surveillance can potentially conflict with the user's value of autonomous mobility and privacy. To reconcile safety and autonomy/privacy, an ideal situation-aware deliberative ATD may be trained to continuously assess safety features of outdoor movements. It may create a context-dependent flexible safety zone around the user, so that the level of safety does not depend on the spatial area within which a person moves but on the user's residual cognitive functions and stress coping abilities, and actual environmental conditions (e.g., traffic, weather, daytime). The user would be considered safe as long as the movement pattern of this person carries the characteristics of safe behavior.

2.3. Technological options and perspective developments

2.3.1. The technical problem

From the viewpoint of technical realization, the concept of situation-aware assistance faces three fundamental

Panel 1
Key determinants of systems' feasibility and usability

System driven

Complexity of functions

High level of functionality increases acceptance for use but decreases usability

→ High-end technology to reconcile functionality with usability (Section 2.3)

Costs

High costs limit broad application of assistive technology devices (ATD) and may hinder further development if profit expectation is negative

→ Cost-efficacy is a major driver for reimbursement; current lack of reliable effectiveness data (Section 3.2) does not yet allow assessment of expected cost-efficacy

User driven

Lack of insight into own cognitive and physical resources

Unrealistic expectations on system capabilities

→ Integration of ATD into an individualized multimodal health care program (Section 4)

Misfit between user capabilities and complexity of system use

→ Self-adaptive ATD detects and automatically adapts itself to the user's level of cognitive capabilities without the need of active user input

Limited ability to learn novel routines

A new ATD will not be used, even if it was potentially beneficial

→ Use of self-adaptive ATD in prodromal stages of dementia, such as in people with mild cognitive impairment, who can still accustom themselves to a novel ATD. The self-adaptive ATD provides attractive functionality for senior users; if the user eventually progresses to manifest dementia, the system automatically adapts itself to the declining cognitive and physical capabilities and delivers more focused support for outdoor mobility

Different valuation of safety versus autonomy features of an ATD by a single user and between stakeholders

Unrealistic expectations on system use, dissatisfaction, and legal action against ATD provider in case of accidents

→ Society-level value sensitive design (VSD) process to generate a broad consensus on levels of autonomy and safety for people with dementia within an aging society (Section 4)

→ Individualized VSD process to expedite the full space of implicit and explicit expectations (Section 3.1)

→ Technological advances toward a dynamic safety concept (Sections 2.3)

challenges: (1) the given situation has to be estimated from sensor data, (2) an appropriate intervention has to be selected, and (3) changes over time (of people and situations) have to be handled. (Key technical terms are explained in the technical glossary, Panel 2.)

Intervention selection for outdoor social mobility has to cope with a wide range of possible situations that are defined by factors such as current location, intended destination, travel plan, mental and emotional state (e.g., stress level, mood, disorientation, intention, goals), and individual safety considerations, which will vary according to cognitive state (more safety is required if wandering or stress behaviors are inferred). However, all these factors are not directly measurable but have to be inferred from observable actions and biometric data, such as motion direction and heart rate variability. Only for systems with a limited operational space and time is it possible to anticipate every situation and select the appropriate reaction in advance by the ATD design engineers during system development. The paradigmatic example is the geofence: the situation is represented by a single bit (inside or outside of geofence), the reaction is: "contact caregiver if outside, do nothing if inside"). This is not feasible for the operational space of outdoor social mobility. Instead, the ATD needs the ability to decide autonomously, on-site and in real-time, which of the different available interventions is most appropriate.

The treble task of situation estimation, intervention selection, and adaptation to change where sensor data is ambiguous, where the space of situations is large, and where autonomous decisions by the system are required, at first glance appears to be technically highly challenging and difficult to achieve. However, there have been several projects using methods from AI, which suggest that providing this level of reasoning by a machine maybe possible.

2.3.2. Functional assistance

ATDs that focus on supporting goal directed, functional behavior, where a person tries to achieve a certain goal such as reaching a destination or working through a schedule, have for some time been on the agenda of applied AI. An early example is the planning and execution assistant and trainer (PEAT) [29] that helped users with brain injuries to keep focused on tasks despite distractions by providing appropriate cues, based on a daily activity plan. As a situation-aware assistant, PEAT would automatically reschedule activities in response to unanticipated changes, such as skipping, adding, or deleting an activity, based on an AI planning algorithm. A second

Panel 2
Glossary of technical terms

Artificial intelligence [42] in the context of deliberative assistive technology devices refers to the development of algorithms that allow a machine to perform cognitive tasks, such as pattern recognition, logical reasoning, planning, selecting actions under uncertainty, and learning form observations.

Theory of mind (ToM) a concept from cognitive psychology that in the context of this article describes the assistive system's model of the cognitive state of the human partner. If a system attributes mental states—such as intentions, beliefs about situations, and desires—to another entity to interpret the observable behavior of this entity, it uses a ToM.

Life space [57]: As a measure of global mobility behavior, life space is an important indicator of physical and cognitive functioning in community-dwelling older adults. Defined as the spatial extent in which a person moves within a specified period, life space is a measure of enacted mobility behavior encompassing the interaction between intrinsic capabilities of the person and the demands of the extrinsic environment.

Markov-logic: A combination of symbolic logic and probability theory that allows application of symbolic reasoning—such as modus ponens (modus ponens: The logical inference rule that allows me to conclude "B holds" in case I know that "A holds" and "if A holds, then also B holds")—even in cases where the truth of individual facts (such as "if A holds then also B holds" and "A holds") are uncertain. This allows the combination of qualitative prior knowledge (logical facts, provided by domain experts) with quantitative statistical data (computed from training samples), thus integrating knowledge- and data-driven methods for analyzing complex situations.

Computational state space models: A combination of symbolic algorithms with probability theory that describes the behavior of complex nondeterministic systems. A reasoning method that, similar to Markov logic, aims at combining knowledge—and data-driven methods, based on a different concept for representing qualitative prior knowledge (precondition-effect rules).

Partially observable Markov decision process (POMDP): A sequential Bayesian model combined with a utility function that allows for decision-theoretic planning over long time horizons in uncertain (stochastic) domains. A POMDP is coupled with an algorithm to compute a policy or strategy of actions for the system. These algorithms, such as point-based value iteration, are computationally very expensive.

seminal prototype using AI techniques for wayfinding is the opportunity knocks (OK) system [30] that, based on a mobile phone and a GPS sensor, aimed at providing situation-aware wayfinding assistance. The system would learn typical routes from observing user behavior and compile them into a dynamic Bayesian network, it would use this network to automatically infer a potential destination from the GPS data at the begin of a route, and it would interact with the user to clarify if a deviation from a route is deliberate (= switch of destination) or unintentional. In contrast to a geofencing system, OK focuses on helping the user to independently solve the problem before contacting a caregiver.

Although PEAT and OK use certain abstract concepts such as "plans," "goals," and "deviations," they do not explicitly consider mental states in situation estimation. Specifically in situations where cognitive factors may be the cause of unexpected behavior, it might support intervention selection if such factors are included in the situation model. A recent study [31] suggests that such an algorithmic theory of mind allows a machine to infer mental states (such as "person has discovered he has forgotten his umbrella and now has the intention to fetch it") from observed behavior ("person has turned back home"). It has been shown that this approach also allows the representation and detection of specific types of errors in problem-solving behavior related to AD, such as failing to initiate, complete, or correctly sequence individual steps in a composite task (see [34], using the kitchen task assessment as the application domain). In cognitive neuroscience, there are three main theories explaining how human beings capture intentions, motivations, emotions, and needs underlying behaviors of observed persons: the mirror neuron system theory that relates to an immediate understanding of intentions and actions of observed persons [32], the emotion perception theory that relates to an immediate understanding of emotions of observed persons [33], and the theory of mind that relates to a higher level cognitive process involving deduction of mental states of observed persons [33] ibid.

2.3.3. *Personality factors*

The approaches just outlined focus on goal directed, functional behavior. The COACH system, designed to help a person during handwashing, also accounted for some basic aspects of a person's mental state by modeling their awareness, responsiveness, and their overall level of dementia [35]. It was found that such systems were technically functional (they were able to track a person, correctly infer what they were doing, and give assistance when it was needed), but they often would not work for specific individuals [36]. It was believed this was due in part to an emotional misalignment between the person and the system [37]. A person may not respond well to a specific type of assistance because they feel it is, e.g., too imperative ("who is this telling me what to do?") or too weak (e.g., "that doesn't sound important to me, I can ignore it"). To address this, the work in [37] makes use of a sociological theory of identity and alignment called affect control theory [38]. Each person has a fundamental sense of self, characterized by how valent (good), how powerful, and how active they feel. The theory says that people seek social situations that allow them to enact this sense of self. For example, a person who feels very powerful will seek less powerful people that they can interact with, so their sense of power is supported. The theory is applied to the assistive context in [37] by modeling this sense of self and the perceived affective identity of the prompting system. The idea is that these models will allow for more effective prompts, and greater uptake of the system, by ensuring that the system respects the affective role or identity that the person is trying to enact. Furthermore, the models are adaptive to a person's changing sense of self. Issues of identity and illness are complex and multifaceted but highly significant for the uptake of treatment or therapy in general [39], and for neurodegeneration and aging specifically [40].

2.3.4. Computational methods

The studies outlined in the previous sections suggest that the basic mathematical methods required for handling the two fundamental challenges of (1) inferring the user's situation from (noisy) sensor data and (2) selecting appropriate interventions are available. They also show that theories which are required for creating situation models that account for function-oriented and personality-related aspects are at least in part available, and that learning and adaptivity are also possible. However, we note that even successful proposals such as OK have not yet found their route into clinical practice. A recent evaluation of systems for assisted cognition [41] indicates that one major problem here might be that such technical ideas have not yet been subjected to rigorous and significant clinical studies that establish their effectiveness (see Section 3.2 in the following). Another aspect, of primary interest from the viewpoint of computational methods, is concerned with the maturity of technology; although the use of situation-aware assistance has been demonstrated in tightly controlled laboratory settings, the complexity of unrestricted everyday behavior within a person's life space challenges current modeling and inference capabilities. Indeed, although probabilistic and decision-theoretic methods such as Bayesian inference for sequential state estimation and partially observable Markov decision processes (POMDP) [42] have for quite a while provided the mathematical foundation for handling situation estimation and intervention selection, the computational complexity of the available algorithms has so far restricted their use to rigidly confined application domains. Confronted with the situation space of everyday mobility outlined previously, existing algorithms take too long to select interventions in real time [43]. It is here interesting to note that OK required 30 days of continuous monitoring to learn only six destinations with a single route for each destination, thus even obtaining the situation space is a challenge.

In this section, we will briefly summarize how two recent advances in computational methods make situation-aware assistance feasible. Note that the usability of such situation-aware assistants is an important subsequent challenge. It needs to be addressed once it has been established that the fundamental computational challenges are solvable.

The first core challenge in situation estimation and intervention selection is the large number (billions) of real-world situations to consider: exact solutions require too much storage and computation time to be feasible. However, when replacing exact computations by approximate, sample-based algorithms, much larger scenarios become possible. The basic idea is to provide a behavior model of the assisted person, use this model to run a large number (thousands) of stochastic simulations in parallel, delete those simulation runs that are impossible given the sensor data, and then use the remaining simulation runs for estimating the person's state. This technique can also be used in solving POMDPs (point-based value iteration [44], used in [36], is one specific instance of these algorithms)—that is, it can be used for computing that intervention which gives the optimal support to the assisted person, even if the situation itself is uncertain. The LaCasa navigation assistant [36] shows that this method can now successfully be used for creating navigation systems that provide situation-aware assistance based on the probable cognitive cause for unexpected route deviations: if the probable cause is disorientation, the system will provide prompts that help in regaining orientation. If the probable cause is adoption of an interfering goal (such as "I have to go to work" for a retired person), a caregiver is informed.

The second core challenge is the need for training data. Methods of machine learning require large amounts of training data for parameter estimation. Specifically with human everyday behavior, this training data are extremely difficult to obtain: one need not only the sensor data, which in today's time of big data might not seem very difficult to get, but also the "ground truth," for instance, the true mental state, which accompanies that sensor data. However, for a while now, strategies have been investigated that allow to build statistical, quantitative models from logical, qualitative information. This would be an attractive solution for the training data challenge as it would allow using existing qualitative "common sense" knowledge on human behavior (such as "in order to cross the street you need to wait for the green light" and similar "recipes" for everyday activities)—encoded into logical statements, as surrogate for training data for obtaining a quantitative estimation model. Here, Markov logic [45] or computational state space models [46] provide new solutions: by allowing real-time situation estimation in situation spaces with hundreds of millions of situations, the associated inference algorithms promise to scale well beyond laboratory examples.

The computational methods outlined previously intrinsically also allow adaptation to long-term changes in behavior. One option is to introduce variables into the situation model that represent such changing values, which are then estimated from sensor data in the course of situation estimation. For example, the COACH system [35] has a representation of a person's awareness. Momentary changes in the person's awareness are inferable from their behavior during the handwashing task. The other option is to change the model itself, either by re-estimating parameters using new data collected in the course of assisting the user or by structural learning, which allows fundamental changes to the underlying model (such as adding variables and dependencies, or formulae for logical models). OK is an early example of this technique that would learn to adapt to new routes. However, how to apply these techniques successfully in ATD in general and which technique is appropriate for what adaptation task are not yet very well understood.

Thus, technological advances suggest that it has become possible to apply the fundamental solution paradigms required for situation-aware assistance to application domains that are as complex as autonomous outdoor social activities for people with mild dementia. However, the complex and dynamic interplay, across a user's social network, of values, needs, and social and emotional factors that underlie many of the major difficulties associated with neurodegeneration in aging remains a major challenge for ATD effectiveness and uptake.

3. Evaluation and implementation

The following sections describe value sensitive design (VSD) as a structured process of technology development to reconcile the values of usability, flexibility, reliability, and support of safety and autonomy (Section 3.1); how the effectiveness of ATDs can be determined in clinical settings (Section 3.2); and how ATDs can be implemented in real-world applications respecting user values and needs, as well as their cognitive and physical resources (Section 3.3).

3.1. VSD to reach an agreement among stakeholders

VSD focuses on social and technical aspects of design, without replacing traditional software engineering. It involves an iterative tripartite methodology that integrates conceptual, empirical, and technical investigations. The conceptual investigation identifies all stakeholders and their main values (Table 2), whereas empirical investigation focus on users, contextual information, and value trade-offs to identify key design values. An interesting application of this methodology [13] unveiled that clinicians were concerned with safety and wanted continuous monitoring, whereas residents were concerned about keeping intrusions of their privacy to a minimum. The aim of that study was to reduce workloads by implementing infrared sensors "to alert staff in case a psychogeriatric patient with a risk of falling, gets out of bed, and needs assistance" [13]. The VSD approach ensured privacy until a motion sensor indicated that the patient was going to rise from their bed. In that case, an alarm was activated, sending a video to the portable device of staff who then made a judgment about whether assistance was required. During the technical investigation, practical considerations forced re-conceptualizations of the outcome of earlier stages (e.g., "flexible safety"). This motivates additional meetings (e.g., iterations through the stages) with stakeholders and users toward an agreement on the features of the ATD to be implemented. Fig. 1 outlines functions of these iterations through the stages to reach compromises imposed by the technical limitations of current ICT.

Of note, in its full extension, the VSD process follows society- and individual-level processes parallel to system development to reach a consensus on (1) the hierarchy of key values an aging society needs to support for people with dementia (for example, at which costs of budget and safety can society provide autonomy for people with dementia) and (2) a trade-off between potentially conflicting values for a single individual (for example, which risks of falling,

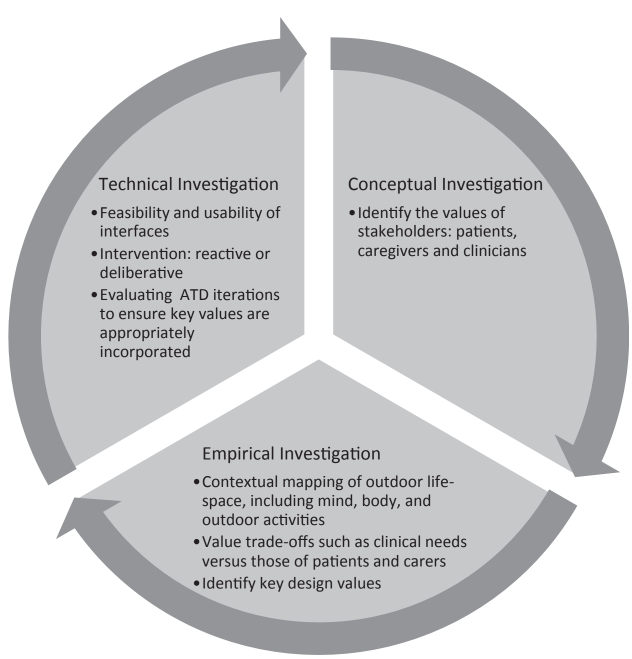

Fig. 1. Measurement of effectiveness of the intervention: Iterative stages of VSD. Abbreviations: ATD, assistive technology devices; VSD, value sensitive design.

getting lost, and so forth, an individual and a caregiver is prepared to take to protect autonomy and privacy). It is a model which has the potential to improve the success of new ADTs from conception to delivery, and may advance the application of ethically driven commercial products translated from the research laboratory.

3.2. Assessing effectiveness of deliberative ATDs

Although the effectiveness of health care ICT interventions is well documented in many applications [47], data on the effectiveness of technical solutions to support outdoor mobility in dementia are still scarce [48]. An open question is how we can measure effectiveness for ATD-based interventions, when we consider the level of socially engaged activity as the primary determinant for well-being in dementia.

As a first approach, studies focusing on indoor mobility considered the successful arrival of the user at a predefined point in space as the primary outcome [5]. As the arrival at an intended goal is a necessary requirement for social activity, such a measure provides a useful marker for effectiveness. In everyday activity, however, flexibility of mobility is a value on its own. If the user during some transition decides to change his/her target, the successful route-completion end point would detect a system failure. Systems that learn the typical life space of a user and automatically detect an intended change from one to another characteristic target within that life space would enable a flexible route-completion end point. Such an end point, however, represents only a surrogate measure of social activity.

The use of ATDs for outdoor navigation may provide more direct measures of their social effectiveness. The integrated activity of a person over a longer period of time, including phases of intended and goal-directed movements, serves as a potential proxy for the quality of social activity. The maintenance or even expansion of a previously detected life space of a person would be a potentially relevant end point to assess the quality of social activity. Early research in this area points to the possibility that features inherent in relatively simple accelerometric measures can be used to derive such information [49]. It seems possible from experimental evidence that movement patterns can be used to identify phases of social interaction, such as attended group activities and attended socially relevant places. In our view, the measurement and validation of such life space end points would be highly effective as part of the development process of the technical system [50].

Another approach would be to assess the quality of life and well-being of the user in consequence of the use of an ATD. This approach has the advantage that it directly measures the most relevant end point for the user. The disadvantage is that it is not clear how this end point can reliably and validly be measured. As stated in a recent Cochrane review [51], "Most measurement instruments [for quality of life] lacked information on hypotheses testing and content validity. Information on responsiveness and measurement error was not available for any instrument." In addition, self-rating instruments of quality of life can be affected with the disability paradox [52]: people with a chronic condition, including dementia, rate the quality of their lives typically higher than people from outside would do. So, self-rating instruments on quality of life often have a ceiling effect; owing to the limited insight of a person with dementia into his/her own impairments, such instruments also are insensitive toward change [53]. For example, a study in 80 people with mild-to-moderate AD dementia found no significant decline in health-related quality of life using a self-rating instrument over 18 months [54]. An alternative are ratings of quality of life and well-being by proxy. This would, however, counteract the idea to support self-efficacy and autonomy in people with dementia when one has another person judging their quality of life. Still, combined measures of successful route-completion together with a rating of quality of life and well-being by proxy may become a relevant end point for effectiveness studies.

In addition to effectiveness, adverse events and safety are important end points for assessment. If an ATD increases mobility, it also increases the chance of falls and other incidents, such as traffic incidents or getting lost. For instance, now in many instances, patients are mobilized immediately after hip surgery, after evidence showed decreased risks of falls and mortality at the mid- to long-term follow-up. Similarly, studies need to assess mid- to long-term outcomes of ATD use in respect to safety end points such as falls and incidents. Increasing rates of falls with ATD use may be a short-term risk that is counterbalanced by reduced risk of falls on the mid- to long-term due to enhanced mobility. Panel 3 presents an operational framework for assessing safety and efficacy of ATD in analogy of the framework of drug development. Such framework is used only in analogy because ATDs do not fall under drug development legislation.

3.3. Privacy and communication

ATDs to support outdoor mobility have the potential to violate data safety. They collect rich data on long-term trends of behavior that are used for the continuous training of situation-aware assistance, and may also serve as early markers of health risks. As long as this information stays with the user and his/her trustee, collecting these data is not threatening data safety rights. However, data on behavioral trends are of potential interest for public or commercial health care providers. Seniors with cognitive impairment are a vulnerable group who will not always understand the risks and benefits of a product or service offered to them. Health care providers may even exert pressure on people with cognitive decline to subscribe to certain services; the health insurance fee of a senior person may then depend on the choice to use or not to use health surveillance technology. Ideally, the data on the user's life space and the intelligence to infer states of disorientation and to intervene would

Panel 3
Framework for assistive technology devices development, in analogy to drug development trials

Clinical trial (nlm.nih.gov/services/ctphases.html)	Assistive technology devices development
Phase 1 Study in healthy volunteers → Dose finding, safety	Study in cognitively intact volunteers in paradigmatic conflicting conditions set up in laboratory and real environment → Side effects due to disfunctioning, erroneous interpretation, and decision making of assistive technology devices (ATDs) in paradigmatic conflicting (i.e., users intentionally change original plan of outdoor transition) and potentially dangerous (i.e., barriers, road blocks, conditions of poor illumination) situations
Phase 2 Study in patients → Safety, effectiveness, side effects	Study in small groups of seniors with mild-to-moderate cognitive impairments in paradigmatic conflicting and potentially dangerous situations set up in laboratory and real environment. → Side effects (e.g., falls, bone fractures, accidents, stress, inconvenience, disorientation, panic, and so forth) due to disfunctioning during interactions with users or erroneous interpretation and decision making of ATDs in paradigmatic conflicting situations → Adherence/use, acceptance, and effectiveness → Efficacy on primary (i.e., successful outdoor transitions, achievement of targets, and so forth) and secondary (i.e., quality of life, outdoor social interactions, etc.) end points
Phase 3 Study in patients → Safety, efficacy, effectiveness, side effects, comparison with commonly used treatments	Larger cohort of seniors with mild-to-moderate cognitive impairments in paradigmatic conflicting and potentially dangerous situations set up in laboratory and real environment, as well as in routine use. → Efficacy on primary and secondary end points
Phase 4 Postmarketing surveillance → Drug's effect in various populations, side effects associated with long-term use	Long-term observation postmarketing in seniors with mild-to-moderate cognitive impairments in routine use. → Efficacy on primary and secondary end points → Side effects associated with long-term use → Cost-efficacy of long-term use

remain within the local device. This is, however, only possible to a certain degree; owing to restrictions in the energy supply and computing power with more advanced services, data will need to be transferred to external "cloud" computers. In these instances, it will be important to implement strict regulations on data protection.

The potential use of long-term trends of behavior as markers for health risks raises the question of how this information can be appropriately communicated with the user. The challenge of how to communicate potential risks to people with dementia has found some attention in the field of genetic counseling for dementia [55], but not yet in the context of information from sensor data. This opens an entirely new field for research on risk assessment and communication in dementia that will become highly relevant with the increasing trend toward ICT-based interventions.

4. Summary and outlook

From the previous sections, we would argue that the need of users for autonomous mobility is not sufficiently met by current ATDs. We identified four key challenges to be addressed on the way toward useful ATDs for outdoor mobility in mild dementia:

1. Novel technologies pave the way toward situation-aware deliberative ATDs. These systems can reconcile potentially conflicting user values of safety and autonomy by creating a flexible safety zone around the user. To become useful, a situation-aware deliberative ATD needs to be tuned to its user's cognitive and physical resources (Table 1, first column), ability to cope with stress, emotional identity, as well as features of environment and life space, and individual preferences for safety and autonomy (Table 2). This tuning may use information gained from formal examination but also from the system's data itself along a training phase (Table 1, third column). Derivation of life space information (including access to web services and repositories, local weather forecast, and so forth) and inferring user preferences from the system's sensor data, and continuous adaptation of the system's functionality to this information, represents a further complexity to the technical investigation stage of the VSD process.
2. Dynamic, real-world situation-aware adaptability is required to meet the goal of autonomous outdoor activity. However, minimization of risks of falling and accidents should be always the first operating condition. Furthermore, ideal ATDs should fine-tune strategies of intervention on a per-situation basis. Ideally, such systems, providing a self-adapting functionality, should be attractive for use already in prodromal stages of dementia, such as in MCI, to ensure accommodation with system use and risks in advance of loss of cognitive flexibility (Panel 1).
3. Situation-aware deliberative ATDs must prove their usefulness within a real-world setting on user-relevant end points. The ATDs themselves provide rich data for life space assessment that may serve as such end points if they are validated against more traditional measures of well-being.
4. There will be no single solution to deal with the complexities of user needs. Technical solutions can unfold their whole potential only within the framework of multimodal interventions that support meaningful social interaction [56]. In the decades to come, we will need an integrative concept of dementia care that fully exploits the potential of ICT solutions for dementia. This gives rise to two main issues. First, human resources for the training and assistance of users and caregivers in the use of these ATDs should be optimized. One solution is to promote the use of these ATDs already at the prodromal stages of dementia, when patients have greater residual cognitive resources and better coping with the stress induced by learning new ICT procedures. Second, diffusion of these ATDs will urge that stakeholders carefully frame their use into a larger context of multimodal interventions that respect the needs of patients and their families to maintain autonomy and self-efficacy.

In this perspective article, we took an optimistic view on the potentials of developing and implementing situation-aware deliberative ATDs for dementia care in the future. The authors are, however, well aware of major obstacles and challenges with this concept. First, an ATD that allows people with dementia more outdoor mobility necessarily exposes the users to potentially risky situation, such as urban traffic or falls. An explicit value prioritization is required to reach a consensus on the risk an individual dyad of user and caregiver as well as society is prepared to accept for supporting user needs of autonomy. Similar decisions have implicitly already been made in many instances, for example, when a frail patient receives active mobilization training (increasing possible instances of falls) instead of fixation to his or her bed (setting both risk of falls and mobility to almost zero). With new technologies, such prioritization processes need to become explicit and transparent for all stakeholders. In addition, development of ATDs has an impact on what financial resources societies are eventually prepared to invest into improving safety for older people in public space, including public transport and automobile traffic.

Second, the usefulness of an ATD will be restricted to a certain time window during disease progression, when the patient is still able to operate the system and at the same time can make use of its functionality. Therefore, systems would be attractive that automatically adapt their functionality and operationability to the user's cognitive capabilities as disease progresses; such systems can usefully be used across several stages of disease. Finally, the authors did not reach a consensus on a crisp timeline of when such systems will be readily available. We will experience a secular shift in technology affinity of the population at risk of dementia as the baby boomers enter the risk age cohorts. This will bring incentives to industry, academia, decision makers, and medical services to develop and implement smart ICT solutions for senior people that eventually become useful in case of cognitive decline. The potential to reduce costs of care with the use of such systems would be a major driver for implementing such ATDs within a health care system. But even without evidence for such an effect, smart ATDs will become more requested by senior customers in the next decade.

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RESEARCH IN CONTEXT

1. Systematic review: The authors reviewed the literature based on PubMed, ISI Web of Knowledge, and meeting abstracts and presentations. We used a qualitative approach of document analysis to screen literature for key statements. These relevant citations are appropriately cited.
2. Interpretation: The literature on information and communication technology (ICT) solutions for dementia appeared of very heterogeneous quality but indicated a decade gap between technological concepts and their evaluation in a clinical context. Our research suggests that the emerging technologies can help to reconcile system complexity with system reliability and user needs for safety with user values of autonomy.
3. Future directions: We propose deliberative situation-aware ICT devices to support people with dementia. Based on adaptive features, such systems can be used along from early symptoms of cognitive decline until moderate stages of disease. The final proof of concept is the use of such technology in ecologic contexts such as primary care settings.

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