1.1 PUBLISHABLE SUMMARY

Context and Objectives

The DALi project aims to develop a mobility aid (the c-Walket) to offer support for autonomous mobility in open and partially structured environments such as shopping centres, airports or train stations. The c-Walker, which senses the environment, plans long term routes interacting with the environment, anticipates the intent of the people in the surrounding and suggests short term courses that minimise the risk of impacts or of other type of accidents. The course decided by the c-Walker along with other important information related to the environment is represented to the assisted person (AP), by a combination of haptic, visual and acoustic interfaces. The intended customers of the c-Walker are older adults with intact mobility who are discouraged to attend crowded places by their declining cognitive and sensory abilities.

Work during the first year and results

WP1: User-sensitive inclusive design

WP1 addresses four long term overall questions: 1) how do older adults act in congested public environments?, 2) how do other agents in the environment react or respond to older adults within shared public environments?, 3) what are the needs of older adults for support when interacting with large shared spaces such as shopping malls or airports?, 4) how can these be met via the design of an intelligent walker?

During the first year of the project, the consortium has carried out a number of activities converging towards these goals, as detailed below. We have developed a pluristic approach to examine how shared-space interaction occurs and to understand the needs of older users involved in the task of shopping. We are keen to determine ethnographically what "shopping" means to older people, and if it is purely practically motivated or if social drivers are also involved. We have also carried out a number of technology tea parties with older adults in both the UK and Spain. This method adapts the focus group method to be more appropriate for working with older adults. We have carried out a number of experiments within an artificially confined shopping environment. The participants were assigned a list of items to collect and, in order to develop understanding of how the activity is planned and executed and how interaction is influenced, concurrent talk aloud protocols were used to capture both the thought and decision making processes.

The main results achieved so far can be summarised as follows.
Overall, the experimental research approach has indicated that in the experimental setting, at least, social rules are followed and that the visual system is a key sensory receptor and factor in terms of finding items, agent awareness and avoidance strategies. This may have implications for the design of assistive technologies that rely on providing visual stimuli as users will divert their attention between two or more compelling and competing stimuli. Participants appear to have used eye contact and their peripheral vision particularly to effectively facilitate negotiation and interaction with other agents within the shared space.
Our preliminary results from these studies highlight that different people have different approaches to shopping, with some working from shopping lists, while others browse. For many it is the social interaction that is important. However, we also found that those who did not currently use non-intelligent walkers would not accept the use of a walker (no perceived need), and current users felt that they would not have the stamina to walk the distance required by large public areas and complained about the lack of seating.
Therefore, perhaps, another way of conveying the potential benefits of the proposed technology may be to propose the notion of a *smart-shopper* or *product finder*. This might allow users to enter their shopping list and be guided in the most efficient manner to the product, thus reducing the time and energy expended.

This approach, involving users in multiple ways during the requirements gathering stage and accurately projecting the potential of the technology to enhance their lives appears to be gaining success. This approach will be maintained throughout the project, involving users at ever. The ethnographic work and tea parties has highlighted a general reluctance to start using assistive technologies such as walkers for the first time. They represent loosing ability to the older adults, however, those who do start to use walkers realise that they provide support to enable older adults to keep mobile for longer. Participants highlight the problem of not knowing where to go both within large shopping centres but also within hospital settings. We are also seeing that for more vulnerable older adults, being in a crowd can be stressful and they try to avoid crowds at certain times. Findings such as these are being translated into requirements for the c-Walker.

WP2: Sensing Technologies

The overall goal of WP2, "Sensing Technologies" is to extract the perceptual information that is required to support all functionalities of the c-Walker platform. During the first twelve months, the work was focused on

- map building techniques (both augmented 3D maps and topological, 2D representations);
- c-vision based, c-Walker 3D localization;
- characterisation of wireless and inertial techniques for platform positioning;
- Smart OCR;
- Estimation of the crowdedness of an environment;
- human detection and tracking, both from static multi-camera setups and from on-board RGBD cameras;
- characterisation of the motion of humans in the vicinity of the c-Walker (position, velocity, etc.);
- head pose estimation both from static multi-camera setups and from on-board RGBD cameras.

The main results we achieved so far are the following:

- 3D map construction and vision-based platform localisation;
- techniques for constructing 2D topological maps;
- extensive testing and metrological characterisation of the CSS ranging technique and initial evaluation of inertial techniques for c-Walker localisation;
- a method for estimating the crowdedness of an environment;
- several methods for head pose estimation using both multiple conventional cameras or a Kinect sensor;
- a method for representing, detecting and tracking humans that are close to the c-Walker and estimation of their position and speed relative to the c-Walker.

WP3: Cognitive Engine

The overall objective of WP3 is to provide the c-Walker with an efficient path planning algorithm and with a robust solution for anomaly detection to support the AP in his/her motion across a crowded environment.

During the first year of the DALi project, a tight interaction with the partners operating in WP1 and WP2 has lead the consortium to the definition of a mathematical model describing the kinematics of the motion of a pedestrian in crowded environment. This model will be validated through the activities of WP1 and will serve as an interface for the exchange of information between the sensing system (WP2) and the cognitive engine (WP3).

Building on top of this model, the consortium has taken on an ambitious development activity aiming for a reliable and resource efficient motion planning algorithm. The solution of this problem requires a long term planner (which suggests the most appropriate route to achieve the user's goals) and a short term planner (which preserves the user's safety while moving along the long term plan). In the first year of activity, the consortium has particularly focused on the short term planner, which is the most challenging in terms of expected research efforts. The solution developed is based on hypothesising plausible paths and assessing

their validity (in terms of probability of having accidents) by using statistical model checking (SMC), as implemented in the new toolset PLASMA (https://sites.google.com/site/plasmasmc). The plausible paths are generated by a *human motion predictor model* that takes input from the sensors and uses global knowledge of the high level goals and of the environment. For the initial stage of development, we have adopted the Social Force Model (SFM) of (Helbing et al. 1995) as a reference model to construct the motion predictor for the cognitive engine. The validity of this model is being validated in collaboration with WP1.

Another important piece of work carried out across WP2 and WP3 is the construction of a 3D representation of the scene where the c-Walker is immersed. The anomaly detection task will heavily rely on such a representation. Besides, the 3D representation will serve as a reference model for platform localization as well as the base layer to collect all kind of sensed information (WP2) for interfacing with the cognition part defined in this workpackage.

The most relevant *results* during the reporting period have been:

- design of a unified data/image acquisition setup that fulfils the requirements of all cognitive activities based on vision;
- preliminary results on 3D model generation for the cognitive engine;
- definition of a mathematical model for the motion of human agents, which will serve as an interface between WP2 and WP3;
- definition of a road map to verify the accuracy of the SFM in describing the dynamics of a crowd;
- development of a motion planning algorithm based on the combination of SMC and SFM;
- collection of simulation data to validate the SFM in a realistic scenario;
- first implementation of the algorithm and optimisation of the code to facilitate the deployment on an embedded platform.

WP4: Human/Machine Interface

The purpose of WP4, "Human/Machine Interface" is to design visual/audio and haptic interfaces that can effectively convey the information on the environment and on the planned route to the AP.

The work carried out in the second reporting period focused on the study of Haptic/Audio signals for human guidance and environment representation.

More in detail, the consortium has studied:

- strategies to gently drive the user along a pre-computed path allowing him/her;
- cutaneous stimuli and synthesis of 3D sounds for the representation of guidance signals and techniques to improve the haptic perception in elderly people.

The results achieved can be described as follows:

- development of a mechanical guidance support to gently direct the user toward a pre-computed path;
- realisation of a prototype of the vibro-tactile bracelet, which has been tested with older adults in order to improve their haptic perception;
- implementation of a set of audio processing algorithm for the sound spatialisation;
- testing of the proposed audio processing algorithms. In this regard, a method based on the Head-Related Transfer Functions has been identified and has then been ported into embedded systems to start the analysis of the computational requirements.

WP5: Architectural Design

The purpose of WP5 is to define a hardware-software architecture that will support the execution of the different functionalities of the c-Walker. After focusing on a preliminary definition of the hardware requirements based on benchmarks (in the first reporting period), the consortium has started to define an

appropriate Hardware/Software architecture, identifying the modules that will run on the c-Walker and analysing/defining their temporal requirements and constraints.

For the hardware part, a preliminary evaluation has been carried out on the PANDA board, which apparently strikes a good trade-off between computing power and energy consumption within an acceptable spatial footprint. However, the possibility to add some CUDA-enabled GPU hardware (which seems to be need by different software modules in our preliminary evaluation) is being considered.

A parallel work is being made on the definition of a suitable software infrastructure. In particular, we are evaluating solutions based on a real—time variant of the Linux Kernel, which promises to fulfil the temporal requirements of the various software modules.

WP7: Dissemination and exploitation

The objectives of this package can be roughly stated as follows: 1) securing a timely and widespread dissemination of the results of the project to the relevant scientific communities, 2) promoting an effective industrial exploitation of the most important technological achievements for our industrial partners and, more generally, for potentially interested European companies.

During the first year period, *the consortium has started several* activities related to each of the two goals. As regards dissemination, the consortium has produced several publications of the early scientific results to workshop and conferences, has developed the website, has held interviews and meeting with potential end users, has created a twitter account and produced marketing material. On the exploitation side, our work has focused on the study of a preliminary business case based on market research and on the evaluation of existing products. The objectives of the business case are twofold: 1) offering a good starting point for the subsequent production of a realistic exploitation plan, 2) shifting the activities of the technical teams towards the solutions that can be expected to receive a warm market reception. In the intent of the DALi management, the potential market opportunities will be considered on equal terms with user requirements in defining the final shape of the c-Walker since the early phases of the project.

The *results* of WP7 activities are:

- A website (http://www.ict-dali.eu), which is used both for dissemination purposes and for the internal organisation of the DALi team;
- a project brochure, which is intended for use in exhibition or public events of different nature;
- several conference and workshop publications;
- a report on the preliminary business cases we have studied.

Expected results and impact

During first year of activities, the consortium has significantly refined and clarified the long—term objectives of the DALi project. This was the result of three converging activities: 1) collection of user requirements, 2) definition of a preliminary business case, 3) definition of the technical background for the different components and associated preliminary cost analysis.

The final goal of DALi is the production of a complete proof of concept for the c-Walker, where most of the different components are integrated, co-developed with the users involved in the project and tested. The c-Walker will have to meet expectations and requirements of different nature: 1) win the natural reluctance toward assistive technology through a set of features of perceived utility (e.g., rest-room localisation, shopping list), 2) provide an effective support to the AP by its cognitive and perceptive abilities, by a smooth human machine interface, and by a constant adaptation to the AP changing intent and emotional state.

The first evaluation of the economic and societal produced in the DoW has been further analysed in WP7. Given the declining age of the European Population, the potential market of assistive devices is certainly

huge. However, the share that can realistically be taken by Information and Communication technologies remains to be seen. In our specific case, a growing body of research suggests that maintaining a sustained level of mobility is key to healthy ageing, while the regular attendance of shopping places (e.g., malls) provides additional benefits for the quality of nutrition and of social relations. So, it can be argued that mobility aids enabling this activity could potentially meet a warm reception. The cognitive abilities of the c-Walker are a key differentiator with respect to similar products, which could represent an important competitive advantage. However, the real impact of this technology will depend on its efficacy (i.e., the quality of the decision taken by the device) and by its proper interaction with the mental dynamics of the AP.

The typical Market evolution of innovative products like the c-Walker, follows an inverted L profile. After an initial phase where the product is developed and a sufficient level of market awareness is created, the product sales take of with quick growth until the maturity stage is reached. To minimise the risks incurred during this process, we will adopt a modular design that allows for an easy customisation of the product as a whole in different market niches and for a separate exploitation of the different components. We have identified interesting market segments (shopping centres, large airports, train stations, bus stations and ports, large hospitals); for each we have sketched business models with a multisided approach to maximise the benefits for every side. An additional possibility that we have analysed is to extend the reach a second level set of market segment that could be exploitable (at least for some the modules): smart homes market, rehabilitation market, senior nursing centres, residences, and the labour market and occupational work.

Website

Additional information on the entire spectrum of DALi's activities can be found on the website: http://www.ict-dali.eu.