D7.2 MARIO 2 Functional Specification

- Final Achieved Functionality

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Executive Summary

This report details the final functionality achieved by the MARIO partners in terms of the capabilities and resources of the MARIO robot. It outlines the user led design which has been followed up with user guided improvements throughout the various Pilot Site testing phases.

The delivered functionality represents the state of art in embodied interaction with People With Dementia (PWD). However, there are a number of areas where improvements are required before a robot system could be deployed to operate autonomously for significant periods of time in the challenging environments presented within the project.

Nevertheless, the approach adopted by the project provides a flexible system that can be tailored to the individual needs of specific institutions and even specific users which has potential commercial advantages.

Lastly, despite the unexpected withdrawal of a key partner mid-way through the project, the partners have delivered almost the entirety of the functionality promised in the proposal and shown the potential commercial viability of the application.

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1. Introduction

This report details the outcome of the integration work and feedback based updating carried out within WP7.1 but primarily within WP7.3 and the resulting MARIO system that has been delivered to the Phase 3 trials at each of the three pilot sites together. However, as is detailed in this report, user led design and feedback based updating cycles were implemented throughout the life of the project. Therefore this report details the final achieved functionality of the system as demonstrated at the final Phase 3 trials carried out at IRCCS in December 2017.

The key outcome of the work leading to the functionality described in this report is a MARIO robot system used to assess how well People With Dementia (PWD) can interact with, and benefit from, robot delivered support functions. The trials were also used as part of the feedback based updating cycles to assess any changes needed in the MARIO functionality in order to improve the assistance that can be provided to PWD.

It should be noted that the title of this document has been changed from the one noted in the DoW ("MARIO 2 Functional Specification") to more closely match the document content described in the Amendment AMD-643808-20 and to more closely match the change in the integration process following the withdrawal of Robosoft from the MARIO project.

1.1. Work Package 7 Objectives

The main objectives of Task 7.1 and Task 7.3 that are covered by this report were as follows:

- The on-going step-wise integration of software modules developed in WP4, WP5 and WP6 to test achieved functionality while supporting an iterative development approach
- The final integration of software and hardware modules on the first prototype systems
- Full system testing
- Roll-out of integrated systems
- Maintenance of an issues, missing features and desirable new functionality register
- The undertaking of feedback based update cycles

This report focuses primarily on the output of the tasks to meet the above objectives, although the penultimate section summarises some of the processes involved.

1.2. Purpose and Target Group of the Deliverable

This document describes the final state of the MARIO system achieved within the project and documents how this was driven by the original user-driven specification document combined with user feedback from tests and trials starting with the first instantiation of the MARIO system that was detailed in D7.4.

1.3. Relations to other Activities in the Project

As stated above, this report documents work integrating the outputs of WP4, WP5 and WP6. The documented work primarily feeds the Phase 3 trials of WP8.

The baseline documents for this report are D1.1, the MARIO system specification document for Pilot 1 and D7.4, the description of the functionality achieved for the first phase of MARIO trials. D1.1 details the intended system for the Phase 1 trials as conceived at the end of the requirements definition work, while D7.4, in contrast, details the delivered system based upon changes resulting from a combination of factors but primarily those of achievable results given the resources and the actual difficulty of the task, some improvements to the manner in which functionality was achieved and some changes in the requirements following early trialling with PWD.

1.4. Document Outline

This document provides a description of the manner in which the functionality of the MARIO system was evolved together with a description of the final functionality. Section 2 describes the initial user led design process. Section 3 describes the development and integration strategy. Section 4 provides an overview of the feedback based updating cycles. Section 5 provides an overview description of the final achieved functionality of the MARIO system. Section 6 presents the main differences between the initial instantiation of the MARIO system and the final achieved functionality while, finally, Section 7 presents the report conclusions.

1.5. About MARIO

MARIO addresses the difficult challenges of loneliness, isolation and dementia in older persons through innovative and multi-faceted inventions delivered by service robots. The effects of these conditions are severe and life-limiting. They burden individuals and societal support systems. Human intervention is costly but the severity can be prevented and/or mitigated by simple changes in self-perception and brain stimulation mediated by robots.

From this unique combination, clear advances are made in the use of semantic data analytics, personal interaction, and unique applications tailored to better connect older persons to their care providers, community, own social circle and also to their personal interests. Each objective is developed with a focus on loneliness, isolation and dementia. The impact centres on deep progress toward EU scientific and market leadership in service robots and a user driven solution for this major societal challenge. The competitive advantage is the ability to treat tough challenges appropriately. In addition, a clear path has been developed on how to bring MARIO solutions to the end users through market deployment.

2. User-led Design: Deriving the System Specification

The System Specification for the MARIO system was derived within Work Package 1 and reported in D1.1 as one of the first actions of the project. The input sources used to produce this were:

- Clinical input on needs of People with Dementia (PWD)
- Technical assessment of achievable results
- The Scientific and Technical Objectives together with the Macro-Level Objectives outlined in the proposal
- The potential capabilities of the proposed hardware platform
- Current best practice

These inputs were then used to form a series of use cases that described all the potential interactions that were foreseen between MARIO and the various actors it would encounter in the trials situations. A total of 9 generic use cases were drawn up, each one with several specific interactions detailed amongst the identified actors and MARIO. The 9 use cases were:

- Configuring MARIO
- Entertaining the User
- Assist the User
- Locate the User
- Monitoring the User
- CGA and MPI assessment
- Reminisce with the User
- User Communication

Figure 1, taken from the System Specification, shows how these various use cases interact with the various actors that MARIO encounters.

These use cases were developed in a cooperative effort between the technical and clinical teams within the project. Within each use case a set of possible interactions were elaborated and agreed and from these interactions a very detailed system specification was developed consisting of a top level of 57 “Key” requirements with each key requirement further broken down into more detailed, actionable requirements.

The interactions were also used to determine the functions that the hardware and software systems would need to perform in order to perform each interaction, which then formed the basis of the Functional Architecture of the MARIO system. Finally this Functional Architecture was mapped onto the proposed hardware architecture of the MARIO robot and a design for a 3-layer software architecture, also reported in D1.1, was undertaken.

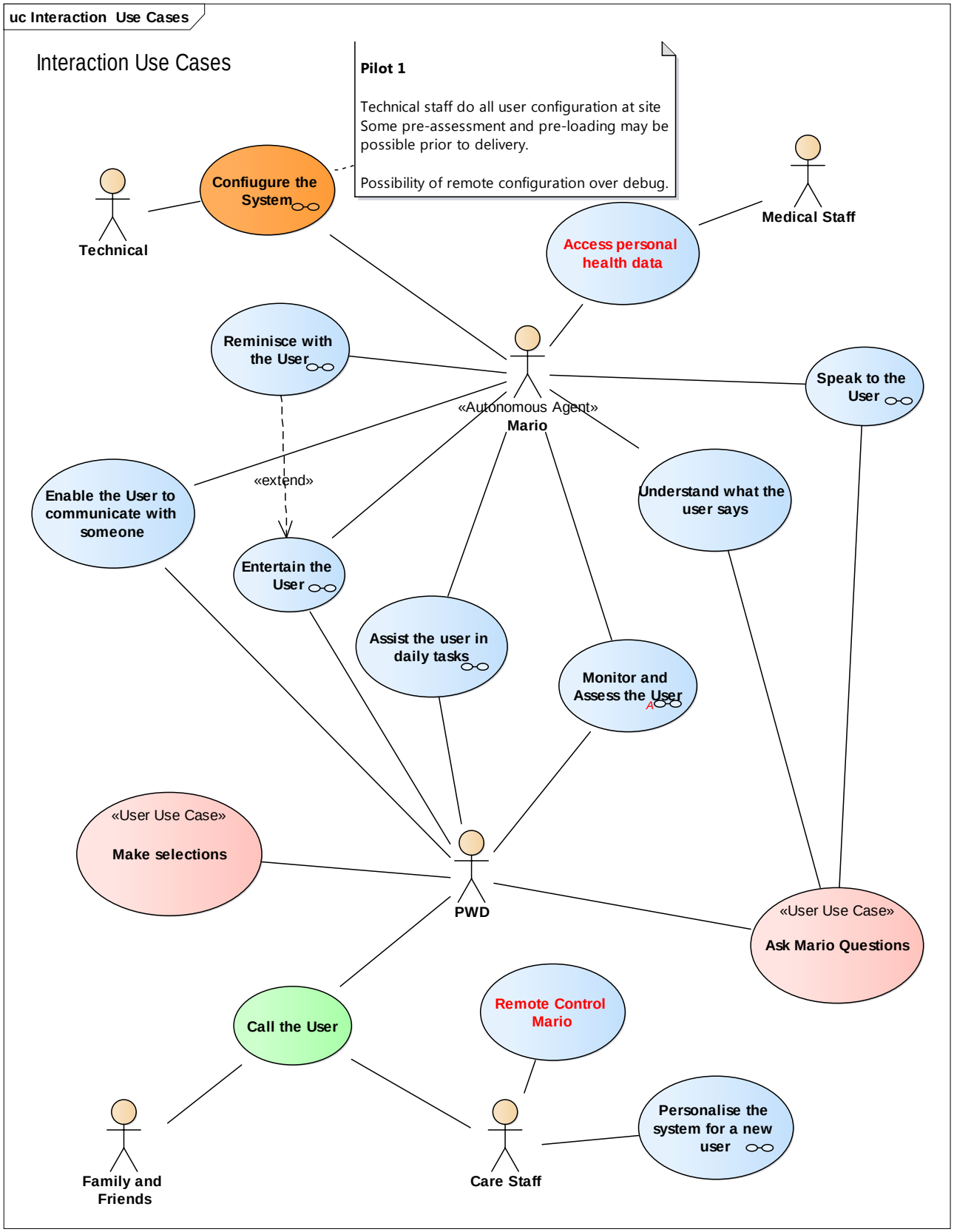

Figure 1 Use Case and Actor Interactions

The 3-layer software architecture consists of:

- a lower layer of system support functions, such as commanding motion, providing external communications and providing database services
- a middleware layer provides the essential “intelligence” underlying the interactions with the PWD and other actors which encompasses the natural language sub-system, the ontology sub-system, the user perception sub-system, the decision management sub-system and the unified user interface
- a top layer consisting of the applications that provide the functionality to the user.

A key part of the architecture design is that the applications provide a flexibility and customisability to the robot. Different applications can be loaded onto the system to configure it to provide services suited to a particular site or even user. The applications also give further flexibility in providing for further functionality to be added at a later stage without a major re-writing or reconfiguration of the robots control system.

3. Development and Integration Strategy

3.1. Development

The development strategy for the MARIO robot consisted of an open collaboration of technical effort from different partners based upon the architecture description developed at the start of the project and reported in deliverable D1.1. As well as the specification and the architecture description, the development was also focussed through the provision of a unified User Interface module whereby all verbal and screen-based interactions with the PWD were presented with a common look and feel.

The development strategy incorporated a user-feedback loop, detailed in the next section and thus was iterative in nature, with improvements being driven by experience in the pilot trials.

For most partners, initial development (particularly of the applications functionality) was undertaken in a PC of Linux environment. However, for certain parts of the CNR developments which had a more intimate connection with the MARIO hardware, e.g. the motion behaviour or the middleware layers, the software was at least partly developed on the robot hardware. This was possible because both CNR sites were allocated a MARIO robot for development. Also, to de-risk the development of motion behaviour, which had been Robosoft's responsibility, a parallel development approach was adopted with both CNR and Ortelio carrying out different approaches to the production of such behaviour. In order to assist Ortelio in carrying out this work, one of the robots assigned to Stockport was temporarily re-assigned to Ortelio.

Each technical partner was responsible for unit testing of particular modules they were developing.

3.2. Integration

The hardware integration was carried out by Robosoft who had responsibility for the electro-mechanical design and build of the MARIO robot. Robosoft design and built the majority of the planned robots but at the time of their withdrawal from the project there were still 4 of the planned 12 robots outstanding. To accommodate this shortfall the trials plan was re-developed to make more efficient use of the 2 MARIO robots now allocated to the 3 pilot sites.

Initially, the software integration activity was planned to be undertaken by Robosoft, as the hardware platform manufacture. The intention was that they would integrate and test the software developed by other partners on an in-house MARIO robot. In the event, Robosoft withdrew from the project before the bulk of the non-Robosoft software was ready for integration. This, therefore, required a different approach as no one partner could fulfil the exact role played by Robosoft. The approach adopted was to undertake, first, partner to partner integration of functionality. For instance as Carretta Net were responsible for the development of the core parts of the User Interface, developers of apps would first perform integration with them and prove the functionality within a PC

environment at both sites. Once tested and verified (which could take several iterations to fix bugs) this was uploaded to the software repository. The software was then remotely downloaded onto one of the MARIO machines, usually at one of the Pilot Sites, for full integration and testing. This required both the remote technical support from the developing partner(s) and support from the Pilot Sites in making the robot available and assessing the functionality.

Following integration of new functionality, the robot was assessed at the Pilot site both for the added / changed functionality and for any unforeseen changes in related functionality. Once fully tested, the new functionality was then available for downloading to the other pilot sites.

Thus the integration process allowed a gradual increase in functionality through a controlled process that successfully circumvents the need for a centralised physical coordinator.

4. Using User Feedback in the Improvement Cycle

An essential part of the MARIO project was the use of user feedback to improve the effectiveness and acceptability of the MARIO robot and its functioning. As mentioned above, this started with user-led design in coming up with the original specification for the first trial configuration which is what drove the original developments. From the point that robots started to be deployed at the Pilot Sites, feedback was generated from users using an Issue Log. Users in this case were deemed to be the project staff who operated the robot, health care staff involved with the trials and, gathered by project staff, the PWD.

The Issue Log is a web based resource that is available to both the project staff working in the Pilot Sites and the developers. As well as tracking each issue, a lead developer is assigned to each issue and the current status is noted. Issues can be cleared through one of procedures, vis:

1. Fully addressing and fixing the issue
2. Noting that no further action is required (meaning that addressing this issue would take more resources than were available)
3. Noting that agreement had been reached that the issue was not to be addressed within the current project (meaning that the issue was not critical to the performance of the trials).

Additionally, issues were assigned a *High*, *Medium* or *Low* priority level. High priority meant that the issue was potentially impacting upon the running of the trial while Low indicated that the issue could be easily worked around or was a “nice to have feature”.

The issues captured ranged from “bugs” in the intended operations, preferences in the way certain functions were performed and requests for different or improved functionality. In total, over the three trial periods 103 issues were noted and reported.

Of the 103 issues, all were resolved by the technical team with the exception of two. These were:

- MARIO reporting that it “Does not understand” when extraneous noise is detected. As noted below, for this particular target group it is not acceptable to have a trigger word before a voice command and therefore MARIO attempts to interpret any noises it hears. Although sematic analysis of the voice to text stream very much improved performance in this area, it was not possible to eliminate this issue, particularly in noisy environments. This is a state of art problem in voice recognition which does not have a general solution. This issue was noted as “No further action required”.
- MARIO’s microphone sometimes stayed on when music was playing and this resulted in MARIO stating that it “Does not understand” occasionally. However, this issue occurred only rarely and was non-reproducible. Due to the low incidence of the issue and difficulty in tracking down the condition that caused this issue to occur it was decided to mark this as “Not to be addressed”.

Overall, about 60% of the issues raised were “bugs” in the intended performance while 40% were requests for change or new functionality from the system. This carry over from user-led design to user feedback led improvements certainly was a critical issue in improving both the effectiveness and acceptability of the MARIO robot with the target group.

5. Achieved Functionality

A series of three trial phases were carried out at the three Pilot Sites. To accommodate the issues noted in the third series of trials and to incorporate some of the planned Robosoft provided functionality that had to be taken on by other partners, a final set of trials is planned to be carried out in IRCCS in December. This section describes the final functionality that will be tested in those final trials.

As noted above the MARIO robot architecture provides services at three levels. It is therefore appropriate to cover the functionality achieved in terms of the main functions that were finally presented in these three layers.

5.1. Low Level System Support

The main functionality provided at the low level mainly relate to sensors, actuators and communications. In terms of the main components, these can be summarised as:

- Database support: Providing the ability to customise the system to a particular PWD in terms of their personal data, preferences, collected data about the person, calendar information, and stored media.
- The speech output system consisting of a proprietary text to speech system together with controls to modify parameters such as speed of speech delivery.
- Access to the robot sensor data, primarily the laser anti-collision data and the Kinect 3D data.
- Access to the robot motor controls.
- System management, notably start-up and shut down behaviour plus the system logger which logs major events reports by the applications. This latter is useful for debugging.
- Robot motion behaviour. This was originally to be provided by Robosoft. However, following their withdrawal from the project it was decided to de-risk this potentially complex functionality by allowing both CNR and Ortelio to develop different versions of the motion behaviour software based on different approaches. In the end, both organisations were successful in producing motion behaviour and the resulting behaviours were then judged competitively. Although both were competent it was assessed that the CNR version would be easier to integrate with the rest of the system and this was therefore chosen to be deployed for the final trials. The motion behaviour is capable of approaching an identified person and stopping within an acceptable distance of the person. It is also capable of performing “follow me” behaviour.

5.2. Middleware

The middleware in Mario is focussed on providing a unified user interaction system for the PWD, the main components of which are:

- The user interface including the graphical user display and input and the speech output. The purpose of this system is to give a unified look and feel to the user experience whichever application is being run. This is an essential component of the MARIO system as it allows the addition of different applications which can utilise the services of the user interface and provide a unified experience for the PWD, thus preventing confusion or surprise while allowing the utmost flexibility in terms of the future functions that can be added to the system. A significant and consistent feature of the MARIO system is that feedback to the PWD is always given with both spoken dialogue and screen text. The user interface also has to be configured to operate in the language of the deployed location. In the case of the MARIO project this meant being capable of operating in both English and Italian.
- The natural language interaction system (described in deliverables D5.6 and D5.7) consists of a proprietary speech to text system, chosen as best in class for performance when run locally, together with a syntactic and semantic language processing system which greatly improves the understanding of the overall system. The decision to restrict the speech input to local processing was based upon both the standards of data infrastructure at the various Pilot Sites together with data privacy concerns about current cloud based services (this of course may change as new data infrastructures emerge, particularly 5G). The other major consideration that determined the way the natural language system was designed relates to the particular nature of the PWD interaction. Whilst most state of art speech recognition system (Siri, Amazon Alexa and Google Home) require a keyword activation (and undertake their processing in the cloud) this is not a reasonable approach for PWD. It is not feasible to impose upon PWD that they first state a keyword before interacting. Doing so would result in many failed communications as the PWD would forget to say the trigger or expect a natural follow up on a conversation without a further use of the trigger word. This creates a unique, and difficult, language interpretation challenge. MARIO is nearly always listening out for potential interactions (except in certain circumstances, like conducting a phone conversation where listening is deliberately turned off) and therefore tries to interpret any inputs received on the microphone. In the first instantiations of the system this proved problematic, particularly in noisy environments, but the subsequent addition of syntactic analysis of the interpreted speech input allows much of the extraneous input to be filtered out. However, this is not perfect, and in particularly noisy environments speech input is not that effective and touch screen input is the preferred method of interaction.
- The ontology network and knowledge base (detailed in D5.1) are the heart of the intelligence of the MARIO system. The MARIO Ontology Network (MON) and Knowledge Base (KB) instantiated from it take inputs from the various applications

and can then be used by the applications to modify their behaviour to best meet the needs of the PWD. For instance in the reminiscence app, speech input is subject to emotion interpretation to detect whether the PWD is feeling positive or negative about the currently displayed topic. Based on that the reminiscence app can ask the PWD further questions (probes) about the current topic or move on to another topic. In the music app the KB can support the detection of trends and the inference preferred music tracks, so that those can be offered first to the PWD. Further than that the KB offers a database on interactions that can be analysed to provide data for the optimisation of both the applications and their manner of interaction with the PWD.

- The decision management system and, in particular, the task manager guides the interaction process and specifies the order in which the various options are offered to the user. The task manager, for instance, controls the approach behaviour of MARIO and, when close enough, offers the PWD some interaction options.
- The user perception sub-system has not been developed as fully as was hoped at the beginning of the project. Currently, partly because of resource issues and partly because of data privacy concerns, face recognition is not implemented. A scheme of user confirmation using RFID tags was implemented but (due to modifications made to the RFID sensors by Robosoft) when the modified sensors were added to MARIO the antenna gain and sensitivity was drastically reduced to the extent that the RFID tags only worked reliably when close to the PWD. Both the face recognition and RFID confirmation are both issues that could be fixed but are now outside of the resource capabilities remaining within the project.

5.3. The Application Layer

The application layer represents the overt observable functionality of the MARIO robot system, although it draws heavily on the underlying layers to achieve its' effect. This is the layer that provides the functionality that the PWD directly interacts with as well as providing the flexibility of customising the capabilities of the MARIO robot to the specific site or PWD and of providing future proofing by allowing new functionality to be added as needed. Finally the architecture adopted provides great flexibility in terms of business models allowing both per application and per use models to be adopted.

The applications as currently constituted are part of the three 4-CONNECT Modules together with the additional Comprehensive Geriatric Assessment module. The constituent applications of the 4-CONNECT modules are:

My Hobbies Module:	My Music; My Games; My News
Community Module:	My Family and Friends; My Calendar
My Social Network:	My Chat, My Memories

However, for ease of accessibility by the PWD, the applications are displayed in three categories onscreen, vis:

- See what is happening around you
- Connect with family and friends
- Play something

5.3.1 See what is happening around you

Current there are two applications within this category. The first, My News (described in D3.4 and D3.1 as Remember My News an extension) reads the news from a pre-configured RSS feed that is set up specifically for the PWD. For instance if they are keen on sports then a sports feed can be set up to give them local news. The PWD can skip forward through the news or stop at any point in time. Specific topics or items can also be selected.

The second application is the calendar application, My Calendar (described in D3.1). This allows the PWD to review events related to them, for example birthdays of relatives or appointments that they may have. A significant improvement that was made in this area as a result of user feedback was that reminders based on calendar events would appear whenever the trigger point was set, not just when the calendar application was accessed.

5.3.2 Connect with family and friends

As with the previous category, two sub-categories are offered here. The first is to see what family and friends are up to, My Family and Friends (described in D3.1). This application relies on previously connected twitter feeds and allows the PWD to select an active feed (person) and read (or listen to) their updates.

The second application offers the capability to call a pre-assigned contact and talk with them, My Chat (described in D3.3). Once the connection is made MARIO switches off its microphone to avoid trying to interpret the PWD's conversation as inputs. Therefore, the PWD needs to end the conversation by touching the screen. This is explained as MARIO not listening in to the conversation.

5.3.3 Play Something

Three applications are currently offered in this category. The first is to listen to some music, My Music (described in D3.4). The music has been pre-loaded by health-care staff and represents the PWD's favourite music. The PWD can either ask for music to be played immediately (in which case the most favourite music, as determined by the MON, will be played first) or the PWD can choose the genre of music played.

The next selection is to play games, My Games app (described in D3.4), which then offers a further sub-menu of games that are available. A number of games are offered, from an extensive choice, depending upon the user preference and the selection of the HCP. This selection of games can be expanded and can further be tailored to the interests of the

PWD. As with music, the games offered can be first offered according to the favourites determined by the MON.

The third selection, termed ‘look at some photos’, is the reminiscence application, My Memories (described in D3.3). This starts a slideshow of photos accompanied by text and speech which prompts the user to respond. However, unlike a normal slideshow, sentiment analysis is carried out on the user responses and, depending on the positivity or negativity of the response, a decision is made as to whether to prompt the PWD to say more about the current picture or move on to a new picture.

5.3.4 CGA Analysis

The final application can only be called up by a Health Care Professional (HCP) and is the Comprehensive Geriatric Assessment (CGA) (described in D4.3). Although not all of the CGA is carried out by the MARIO robot, a significant proportion of the ordinary question and answers part is performed, which potentially is a large time saver for the Doctor or other HCP that would normally perform the whole task and is a key economic driver for the uptake and use of a companion robot such as MARIO.

The CGA app goes through a number of questions with the PWD and records the answers given either verbally or on the touch screen. One of the challenges in this area has been providing sufficient latitude to the interpretation of general knowledge questions, particularly given the variety of ways of pronouncing proper nouns and regional accents.

In addition MARIO was given the capability of collecting ambient sensor data in the form of Fitbit watches worn by the PWD which was collected and transmitted in an anonymised fashion but which was capable of being queried by HCPs in a flexible and in-depth manner for each PWD.

6. Differences from Initial Functionality

The differences between the final functionality and the initial (Phase 1 trials) functionality can be summarised under 3 separate headings, vis:

- Missing functionality
- Removed functionality
- Added or changed functionality

6.1. Missing Functionality

Due to the unforeseen circumstances of the withdrawal of the main platform supplier (Robosoft) from the project and the consequential reassignment of responsibilities to other project partners, the expected functionality for the Phase 1 trials was considerably reduced. The major items that were missing at this stage were as follows:

- CGA Application;
- My Chat (Phone) Application;
- Reminiscence Application;
- My Friends and Family Application;
- Motion Behaviour, i.e. the ability to approach a PWD to engage in an interaction and, when appropriate, follow that person.
- Adaptive behaviour, i.e. the ability of the applications to adapt to the responses of the PWD
- Use of ambient sensing for health related data

All these functionalities were added to the final instantiation of the MARIO system. The only significant functionality from the original requirement specification that was missing in the final system was autonomous docking behaviour. This was not able to be implemented due to the very late delivery of the docking stations by the Robosoft sub-contractor who built the systems.

6.2. Removed Functionality

No functionality was removed in its entirety from the final system. This is seen as an endorsement of the original user-driven design approach.

6.3. Added or Changed Functionality

Many improvements were made to the functionality of the originally delivered MARIO system. These were entirely driven by the feedback based update cycles operated through the Issue Log. Many of these were minor functionality changes (e.g. the ability to

edit the text associated with pictures displayed in the Reminiscence Application) but the more significant changes to functionality included:

- The use of semantic and syntactic analysis to improve the speech recognition performance. This is a key advance of the MARIO system where the nature of the target group means that reliance on trigger words cannot be countenanced. The improvements in speech recognition have resulted in a system that is now fit for purpose, albeit that the problem of noisy environments is still a major open research problem.
- The use of emotion recognition triggers has enabled a wider range of adaptive behaviours to be built into the applications and increased their ability to react appropriately to users' responses.

7. Conclusions

The final functionality of the system achieved with the MARIO system represents in many areas the state of the art in terms of a robot system that can offer useful functionality to PWD and to HCPs. In order to achieve this the project partners have had to overcome several challenges specific to PWD and have delivered a system that, whilst not yet market ready, is a good step towards proving the usefulness of robots in support of PWD.

The user led design and iterative user guided improvements have proved essential to get a system that operates effectively in the Pilot Sites and which engages with a wide spectrum of users with different levels of dementia.

Specific challenges of interacting with PWD have been addressed successfully within the project. One notable feature is the handling of speech inputs without the use of a trigger word, as it cannot be expected that PWD will remember to use such a word. This requirement alone sets the MARIO system ahead of many world leading speech understanding systems in terms of the target application group.

Lastly, despite the unexpected withdrawal of a key partner mid-way through the project, the partners have delivered almost the entirety of the functionality promised in the proposal and shown the potential commercial viability of the application.