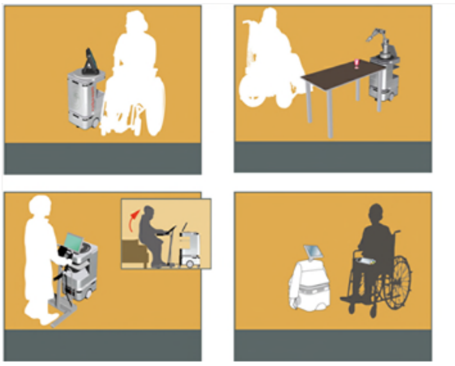

DOMEO Project
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D4.1 Basic Functions Lab Test Report

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Table of Contents

1 Introduction

This deliverable covers the first step from a laboratory prototype of the Domeo RobuMATE AKA "Kompaï" to a user-ready device. It reports the results of laboratory tests with the prototype in realistic use scenarios to assess

- Performance during use scenarios
- Safety and comfort of end users

before end users trials with the prototype (basic functions) are started. There will be another laboratory test report D4.2 including the test results of advanced functions developed in parallel with the user trials, for which only a short report about the development progress is given herein by partner ISIR.

NOTE: this is a preliminary version of the D4.1 deliverable based on a pre-final prototype describing mostly the tests done at TUW. Tests were also performed at partners BME and CHUT. Development of advanced functions was done at ISIR.

There is a dedicated deliverable D4.0 for the robuMATE prototype. The recommended use scenarios and the underlying functionality are described in deliverable D1.3. A description of the methodology for field trials can be found in deliverables D2.1 and D2.2. The investigation plan for the field trials can be found in D7.1.
In this deliverable, where appropriate, suggestions for improvements of functions are given after presentation of the laboratory test results.
The reported resulting performance of the prototype is related to reliability and usability of the set of functions planned for the user trials. Therefore, the different functions were tested especially in close to everyday use scenarios under varying conditions apart from the technical verification done. Not all functions were available yet and not all functions currently present are foreseen to be used in field trials. Therefore both, the set of available functions and the list of functions planned to be used in the field trials, are addressed in this report.
The goal was to find out if there might be any unplanned situations leading to an interruption of service or to states with unclear result for the user.
No final assessment of the achieved performance could be performed because of the lack of clear metrics and a final specification.
Safety and comfort of the end users is a topic of special importance for this kind of robotic assistants going beyond the mere checking of technical performance parameters. The upcoming ISO standard 13482 [12] was used as a guide for some of the verifications.
Note that a full additional risk assessment will be made independently and documented in deliverable D4.3.

2 Prototype setup

This document describes laboratory tests with the robuMATE prototype AKA Kompaï as shown in the following picture:

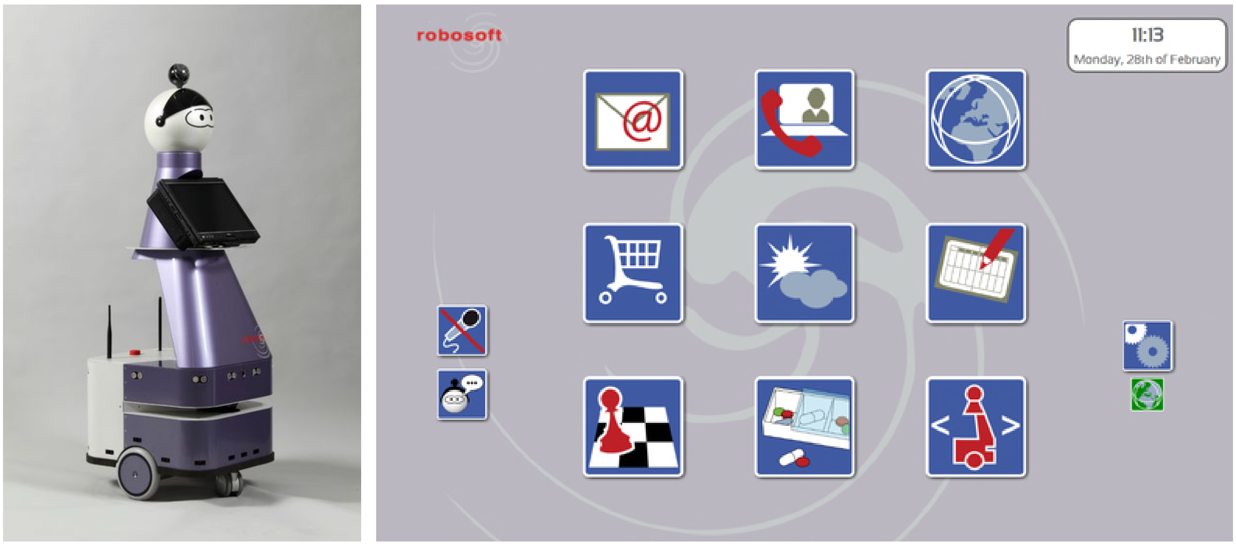


Figure 1: RobuMATE prototype and HCI/HMI main menu on Touchscreen PC (Tablet PC)
(pictures show pre-final versions)

The RobuMATE prototype platform and the embedded control software were manufactured by partner Robosoft. The Open Source software RobuBOX developed by partner Robosoft is based on the Microsoft Robotics Studio and handles the software layers from HMI down to the platform running on the Tablet PC. It was continuously updated and modified throughout the course of WP4 so that many problems found during the lab tests were already solved with updates of the software.
The RobuMATE was set up in the recommended way with a WLAN connection to the internet and a VPN connection to the Lokarria server for remote access [see manuals].
The Tablet PC was running Windows 7 with a modified power supply directly from the robot batteries (DC/DC converter). The language setup was for English (reference) but a German localisation was already tested earlier.

Deliverable D1.3 defines the main user trial experiments:

- X1: Doubt removing in case of needed help
- X2: Tele-consultation
- X3: Socialization, through enhanced communication capabilities

and lists the recommendations for service implementation:

- Scheduled functions based on the personal "routine". These functions will be scheduled on-board (not through internet):
  - F1: reminders (medicines, appointments …)
  - F2: go to the docking station when battery level is low
- On-demand functions :
  - F3: Skype, with only 2 or 3 contacts
  - F4: Tele-consultation with doctors
  - F5: Aid call (button)
  - F6: Navigation to PoI(Point of Interest). Manual control is not allowed.
  - F7: Some website access (weather, shopping list, agenda, games ...)

- Speech recognition F8: robust and easy to use by simple keywords (not more than 20)

3 Scope of testing

Several frameworks have been proposed in literature to assess the outcomes of assistive technology work. The names, number of items and groupings of the topics vary between the proposed frameworks. [13].
In the scope of this report the utility of everyday use of a robotic assistant from the viewpoint of the user is composed of several aspects (end user criteria):

- Availability and reliability
- Usability
- Acceptability and predictability
- Motivation and Fun
- Safety

Other associated aspects, like repairability and affordability, are not within the scope of this deliverable but important for exploitation planning. One very important term in the context of this deliverable is usability. ISO 9241 defines it as "the effectiveness, efficiency and satisfaction with which specified users achieve specified goals in particular environments", where effectiveness means the accuracy and completeness with which specified users can achieve specified goals in particular environments, efficiency looks at the resources expended in relation to the accuracy and completeness of goals achieved and satisfaction measures the comfort and acceptability of the work system to its users and other people affected by its use.
For the scope of DOMEO the specified users are older adults living alone in their home environment and to some extent their relatives and carers.
As a complementary step the evaluation in laboratory includes the task of comparing the functional performance with the specified performance.

In the following, first the test results related to above listed user aspects will be described including assessment of specific sub-aspects. The ordering thus is not related to the functions themselves but to the expected aspects of use. A list of results ordered by user activatable function on the HMI and by the functions defined for use scenarios is provided in the last chapters of this document.

For simplicity, in addition to the textual description of the results some symbols will be used to express the assessment of the results:

☑ for results that are considered sufficient
⍓ for functions that should be improved and/or need further observation
☒ for missing or insufficient essential functionality
➔ marks suggestions for improved or additional functions

3.1 Availability and reliability

The application of a robot only makes sense when the provided service is available in a reliable and predictable way whenever it is needed[1]. Of course, this must take into

[1] There are currently trends to make robots behave more natural and give them some personality, which makes them less predictable but not less reliable

account the necessary re-charging and maintenance time needed for such devices. The first goal of the deliverable therefore was to assess, if the operating time between charging would be sufficient for practical use in the home of a user. In the beginning of the test there were separate supplies for the robot and the Tablet PC. Later on, the power of the Tablet PC was provided via a special adapter by the robot so that only one power supply is needed for charging. This will be the default for the robots for the field trials.
The Tablet PC has a built-in battery that lasts for appr. 2 hours, so that even in case of power failure of the robot there is a sufficiently long time where the system will maintain the operation of the HMI to allow for a service call and feedback to the user. The laboratory test environment comprised of several rooms connected by a long angled hallway where the robot was sent back and forth between stored positions. See "Navigation" for a room map.

3.1.1 Charging and runtime

As a simple rule for 24 hours operation, a certain non-interrupted, continuous runtime requirement, in other words operating time between the need for recharging, has to be demanded for the active time of the day (the time the user normally is awake and might interact with the robot). The requirements may vary with use scenarios, but in general it is unlikely that the robot will be in continuous use for more than a few hours. Longer breaks in the normal use pattern can allow the robot to recharge itself on a special docking station, provided there is sufficient time to go to the charging station and for charging to take place. During daytime, some sufficiently large breaks for partial charging can be assumed to exist, but in general the main part of the daytime should be available for use, while during night time longer pauses are much more likely, so charging overnight is considered most relevant.
Testing was based on a modification of the charger for the Tablet PC by using a 3rd-party charger with 24V input from the robot's battery together with the proprietary Dell charger cable with built-in ID chip.
The testing was performed in two ways: time for full charge of an empty battery was measured and the time available for continuous operation with full charged battery when travelling back and forth between two points was identified. The docking station could not yet be tested.
Note that due to the system being not switched off during charging the continuous idle consumption causes longer charge times than in the switched off state.

3.1.1.1 Results

- Continuous runtime with full battery: 8-9h ☑
- Time for full charge: 6-7h (not switched off) ☑
- Automatic driving to charger: not yet implemented
- Docking (advanced function to be tested): not yet implemented
- Continuous travelling back and forth: 8h ☑
- Reserved operating time of Tablet PC additional to robot: 2h ☑
- HMI speaks warning at about half battery level and informs about the possibility to send the robot to the charger ☑

➔ A service alarm (optional) should be automatically issued if proper charging doesn't occur in time ☐

With a SW update the state of battery charge was made available in the HMI. Automatic charging is planned as an advanced function. As can be seen from above figures, for a 24h operation several recharge cycles will be needed per day, with some idle time spent in the charger. A total full available time of no more than 12 hours (outside charger) can be achieved because the relation of active time to charge time is near 1:1. Because the robot remains active during charging, all functions except the driving are still available but only in a fixed location.

3.1.2 Floor conditions

The robot basically relies on odometry for its localisation. This means that any slipping of wheels because of floor conditions can cause problems in driving to a goal. Additionally, small curbs, steps or similar unevenness of the floor (also cables) up to a certain limit should be similarly manageable by the robot. Tests were mainly made on a floor with plastic tiles, on stone tiles or parquet floor, all waxed and thus somewhat slippery.

3.1.2.1 Results

Although some slipping obviously happened, this caused no problems because of the correction of localization provided in the long term by the matching of the laser scans to the map. A small step of 5mm height with rounded edges between rooms proved to be no problem even when accessed from different angles. Cables on the floor up to a diameter of 1cm usually were managed well if they were sufficiently fixed to the floor. The robot may be slightly misorientated (orientation error) for a short distance after passing such obstacles. If the robot is starting from standstill there are problems with steps higher than 0.5mm, at cruising speed 1cm are managed. A 2cm step is too high to manage it with the front wheel.
No tests on carpets were made. It is expected that the borders of an, especially thick, carpet need be fixed to the floor in order to prevent problems.
If the test environment is checked accordingly for conditions no problems are expected. ☑

Figure 2: tests for passing of ramps and steps done at BME

➔ There should be measures to detect blocking/slipping/spinning wheels

3.1.3 Navigation

The tests were made in a rather cluttered laboratory environment consisting of 3 fully explored rooms with lots of desks and tables, chairs, doors, a glass door and open storage racks as well as potentially open doors leading into unexplored rooms. There is a long angled hallway connecting all the rooms. During some of the tests people where moving around.

Figure 3: Room map. The yellow area was actively used. Red marks show doors to pass.

3.1.3.1 Results of Localization

The robot relies on the information about the travelled distance from the wheels (odometry), which seems to work very reliably but of course suffers from the accumulated error (e.g. because of slipping of wheels) over time, plus a position correction by the laser distance scans matched against the map. The first versions had problems increasing with influence of the correction. Especially in situations where (presumably)

- The map or reality contained (in the frontmost part?) very cluttered/detail rich elements
- A corner, protruding edges or long empty wall was involved

the robot's orientation was prone to be miscalculated. During (fast) driving this seemed to get worse while in standstill the error was slowly corrected. Already at standstill the position displayed was jerky with small jitter and infrequent bigger jumps.

- A software update removed most of the problems. Even in cluttered, changed and partially explored environment the robot now knows and keeps its position with high accuracy (see also tests for driving to pre-defined goals). Every now and then in complex environment still some irregularity was observed so further testing is required.
- Self-localization doesn't work reliably when the robot starts from an unknown position or after massive disturbance. The current position then has to be entered manually which doesn't always work because of the attempted automatic correction (position wanders). A reliable operation can thus only be expected if there are no massive irritations to be expected and the known position of the docking station is used to reset the localization, especially at start-up. The inclusion of some additional hints like low probability for positions inside walls could be helpful to improve this function.

3.1.3.2 Results of passing doors

One of the challenges of robotics is the passing of relatively narrow doors (≤80cm) and passages – "narrow" compared with the robot radius plus safety margins.

- Passing doors worked well throughout all the tests. The minimum width of doors that worked with the given setup was dictated by the settings for collision avoidance (stop area) plus localisation jitter. ☑
- The robot was able to automatically pass door openings down to 55cm with 65cm being the lower limit for reliable operation. ☑

It should be noted that doors that are not fully opened all the time form an unsurpassable obstacle for the robot because there is no special consideration for procedures where the end user will open a door before the robot can pass through.

- ➔ There could be some measures to detect closed doors and ask the user for help?
- ➔ Optional add-ons, like e.g. a remote controlled door opener could be helpful (http://www.abotic.at)

3.1.3.3 Results of driving to predefined goals

The HMI setup allows the definition of named goals by saving specific robot postures (PoIs). The navigation to these goals mostly worked well, although first there were spurious problems caused by a misguided localisation.

The accuracy of localization need be taken into account when e.g. driving to a predefined goal for the purpose of bringing information to the user. While the exact position up to the centimetre often is not important, an accurate rotation angle will be most desirable for the HMI facing the user. On the other hand, if driving to a position very close to e.g. a table or sofa, the orientation might be less problematic than the exact distance. The goal of these tests was to find out which variations are to be expected typically for reaching a predefined goal.

More tests about obstacle and collision avoidance can be found in the chapter about Safety.

<u>Repeated travelling between goals:</u>

The following shows the resulting positions of the robot for repeated driving between 2 predefined goals. Markings are numbered per run for both corners to be able to detect rotation and translation offsets by assessing the connecting red line.

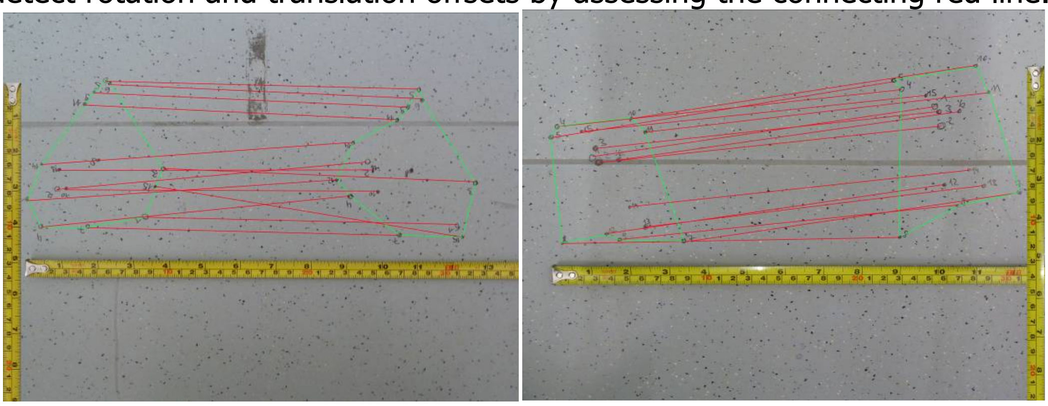


Figure 4: Position hit patterns for repeated positioning between two PoIs

The red lines are parallel to the rear robot edge and connect the dots produced by the stair sensors. It can be seen that the orientation angle varies by ~ 10°, the width of the pattern is ~ 10cm in both axes. The spread of the pattern has to be taken into account when goals are defined because it defines the limitations in the accuracy of positioning.☑

3.2 Usability

The interaction between user and robot is handled via the HMI on Touchscreen PC. Most of the usability questions therefore are related to the HMI. Because of the combination of visual and audible modes in the HMI, a good basis for the interaction with the user exists.

The tests concentrated on the two main questions:

- Accessibility of information presentation and functions
- Clarity and memorability of HMI information

Besides this, the underlying functionality was tested but not assessed as such.

The finer elements of usability as defined by ISO:

effectiveness: accuracy and completeness
efficiency: the resources expended, learnability and memorability
satisfaction: the comfort and acceptability

as well as another proven usability framework - Nielsen's Ten Usability Heuristics [14]:

1. Visibility of system status: The system should always keep users informed about what is going on, through appropriate feedback within reasonable time.
2. Match between system and the real world: The system should speak the users' language, with words, phrases and concepts familiar to the user, rather than system-oriented terms. Follow real-world conventions, making information appear in a natural and logical order.
3. User control and freedom: Users often choose system functions by mistake and will need a clearly marked "emergency exit" to leave the unwanted state without having to go through an extended dialogue. Support undo and redo.
4. Consistency and standards: Users should not have to wonder whether different words, situations, or actions mean the same thing. Follow platform conventions.
5. Error prevention: Even better than good error messages is a careful design which prevents a problem from occurring in the first place. Either eliminate error-prone conditions or check for them and present users with a confirmation option before they commit to the action.
6. Recognition rather than recall: Minimize the user's memory load by making objects, actions, and options visible. The user should not have to remember information from one part of the dialogue to another. Instructions for use of the system should be visible or easily retrievable whenever appropriate.
7. Flexibility and efficiency of use: Accelerators -- unseen by the novice user -- may often speed up the interaction for the expert user such that the system can cater to both inexperienced and experienced users. Allow users to tailor frequent actions.
8. Aesthetic and minimalist design: Dialogues should not contain information which is irrelevant or rarely needed. Every extra unit of information in a dialogue competes with the relevant units of information and diminishes their relative visibility.
9. Help users recognize, diagnose, and recover from errors: Error messages should be expressed in plain language (no codes), precisely indicate the problem, and constructively suggest a solution.
10. Help and documentation: Even though it is better if the system can be used without documentation, it may be necessary to provide help and documentation. Any such information should be easy to search, focused on the user's task, list concrete steps to be carried out, and not be too large.

are forming the basis for the structuring of the following analysis with special emphasis on accessibility by old persons.

3.2.1 Accessibility

The HMI is presented on a 15" touchscreen offering automatic illumination-dependent brightness adjustment. The EN ISO 9241 [3] is the basis for all HMI related usability considerations. Recommendations for the minimum viewing distance between user and display are from 400 to 600 mm. ISO 9241-3 recommends 400 mm for normal office work and states:

> "Character heights from 20 to 22 minutes of arc are preferred for the most tasks. The minimum character height shall be 16 minutes of arc."

A value of 500 mm for the viewing distance is more appropriate given the near point of accommodation at the age of 50 [4], so this is recommended in ergonomic literature [5]. This harmonizes well with the operating distance of touch screens.
Assuming that text is viewed orthogonally so that the viewing distance is at a right angle to the screen, the resulting preferred character height for d = 500 mm is a minimum of 2.3 mm (e.g. an "E") for normal sight. Note that the reading distance is also related to the acceptable personal space distance (see below).

The arrangement of the icons and texts on the screen can be considered appropriate given the size limits and design rules are respected throughout the menu structure so that

- no informational element (especially text) is smaller than a minimum readable size of 3mm height (for 500mm viewing distance). Considering old end users the size should be >5mm.
- fonts are clear (e.g. limited use of bold and italic, never with small fonts, not for essential information)
- all operational elements (buttons, input fields…) are at least 1cm x 1cm (size of fingertip) and clearly marked or recognizable as such
- no elements are distinguishable only by colour
- foreground/background contrasts (grey scale) are good
- the meaning and purpose of the different menus and dialogues and their elements is clear

Currently some of the elements, especially the special function dialogue buttons, are too small, italic font in the lists are hard to read. Touchscreens are known to lack tactile feedback, the good audible and visual feedback provided is therefore very important.
The latest prototype version also has a SOS call button on the front that could not yet be assessed.

3.2.2 Clarity and memorability

This area deals with the issue of providing clear and enough information to the user to understand

- what the system is showing/speaking (especially in case of popups, alerts…)
- which menu/icon to choose for to trigger a specific action

The system uses a clear colour scheme for the menus with each menu having a clear distinctive title. Because of the different colours, it can be assumed that the users

will remember more easily which page is displayed ("the red one"). The icons in the main menu for selection of the different sub-menus are sufficiently big and clear, although instead of the uniform colouring a connection to the colour of the target page might be helpful. ☑
The audible reminders should be accompanied with a switch of the menu page displayed so that additional information can be found on the screen in case the audio reminder is not understood.
The language of the HMI tested was English and a translation was made into German. It has to be noted that language based ambiguities need to be taken special care of. It is not trivial to ensure that a certain context of use (locally different!) is correctly expressed in another language.

3.3 Acceptability and predictability

It is very important that the potential assistance is offered and provided in an acceptable way. This includes that the offered service is nonintrusive so that the user retains the freedom to choose instead of feeling forced and the robot observes to keep outside a certain magic distance to the user to facilitate interaction without intrusion into personal space. In the same way it is important that the user is not surprised by an action taken by the system and is fully informed about the purpose. This is very important with fragile old persons who could be endangered to fall when performing evading movements instinctively. This is also tackled under the Safety chapter.

3.3.1 Information and predictability

The HMI, mostly by speech output, but at the same time also by showing on the screen, informs the user

- About the state of the system and possible actions that can be chosen
- Reminds the user of actions to be performed
- Warns in advance of actions about to be performed by the robot
- Shows any errors or problems encountered
- Informs about the completion of actions, successful or not

A careful balance between useful repetition of information and causing annoyance as well as an adjustable timing are required. Sometimes an escalation strategy is required to deal with ignored reminders to properly emphasize the importance of a user reaction with increasing delay of confirmation.
There are externally induced events (telephone call, battery low etc.) but there are also periodic events like weather information and medical reminders that interrupt the HMI state. This should be taken into account by the HMI e.g. a reminder should be postponed if the user is currently using another menu page. ⍓

3.4 Motivation and Fun

The HMI provides the user with the possibility to play some games on the Tablet PC screen. The size of the game elements on the screen however, is considered almost too small to be really usable with the finger.
Besides this direct fun factor, the HMI makes use of slightly varied spoken messages and can provide reminders motivating to call some friends, take medication, perform

gymnastics, going for a walk, not forgetting meals and drinking enough water etc. based on a fixed schedule.
Some additional features could be implemented to allow the definition of typical activities that can be triggered under certain conditions with some frequency instead of according to a fixed schedule.
As an example, given good weather conditions and the user having been home for long could be recommended to have a walk, to open the windows, to exercise etc. Similarly, an offer could be to play a game, hear a song, call a friend (that is online) etc.

3.5 Safety

In this deliverable the safety requirements of ISO/DIS 13482 are verified by the following proposed methods:

- B: Practical test
- C: Measurement
- D: Observation during operation

Special attention has been given to the topics:

- 5.6 Stress, posture and usage hazards
- 5.7 Stability, especially Instability during travel
- 6 Safety performance requirements, especially Stop and Collision conditions

There will be additional input by the deliverable D4.3 "Risk assessment ISO 13482".

3.5.1 Obstacle avoidance

The operation of the robot relies on a fixed map of the environment for self-localization, path planning and obstacle avoidance. It is possible to add a second map with artificial obstacles causing the robot not to make use of certain areas where the floor conditions (e.g. ventilation grids) or obstacles not detectable by the robot's sensors (e.g. wide tables, low plants) would result in the operation being unsafe.
In addition it is important for the fulfilment of the driving tasks that unexpected obstacles that block the planned path lead to a re-planning of the path with the goal to smoothly and safely drive around them as long as there is sufficient space. This is important both, to eliminate the influence of persons walking around and to ensure that the robot doesn't get stuck too easily and thus cannot perform its tasks. It is also important that the robot keeps a safe distance to all the obstacles also during such manoeuvres.

3.5.1.1 Results of obstacle avoidance

- The robot plans a basic path well away from any obstacle in the map ☑
- The HMI tells the user that there is a problem if no path can be planned ☑
- The robot re-plans the path around the obstacle if there are unexpected obstacles during driving ☑
- The robot stops in front of unavoidable obstacles when re-planning isn't successful ☑
- The HMI tells the user that there is a problem following the path ⌺ - not always, timing? no clear information given?

3.5.2 Stairs and depressions in the floor

The robot has special sensors on its corners for the detection of the floor. If any of these sensors does not detect the floor (i.e. there is a hole or depression in the floor, a down-leading step etc.) the robot is instantly stopped ☑.

- ➔ There should be some means to inform the user about the cause of the stop?
- ➔ It seems that the robot doesn't resume normal operation after such emergency stops

3.5.3 Collision avoidance

Normally the robot should avoid collisions by either re-planning a path around obstacles, detecting that there is no free path, or stopping already in a safe distance before there is a collision. As an ultimate safety measure however there has to be a mechanism which causes to immediately stop all robot movement when the distance to any obstacle unexpectedly falls below a critical distance. Because the robot does not have any sensors on the backside, it has to be assured that any movement does not involve a movement deeper into the blind spot in the back, so only rotations in place or forward movements are allowed.
Under certain conditions this can lead to the robot getting trapped in conditions where there is not enough space in front and lateral to withdraw from such situations even when ordered to a different goal. This would lead to no safety infringement as such but cause an unplanned service interruption. Especially the inherent uncertainty of localisation (see 3.1.3.3) can lead to these cases so that a hysteresis function should be provided: when travelling normally the robot stops in a safe distance before a collision occurs but it is allowed to leave such situations at low speed even when it needs to go a small amount closer to the obstacle (safe distance ± delta).

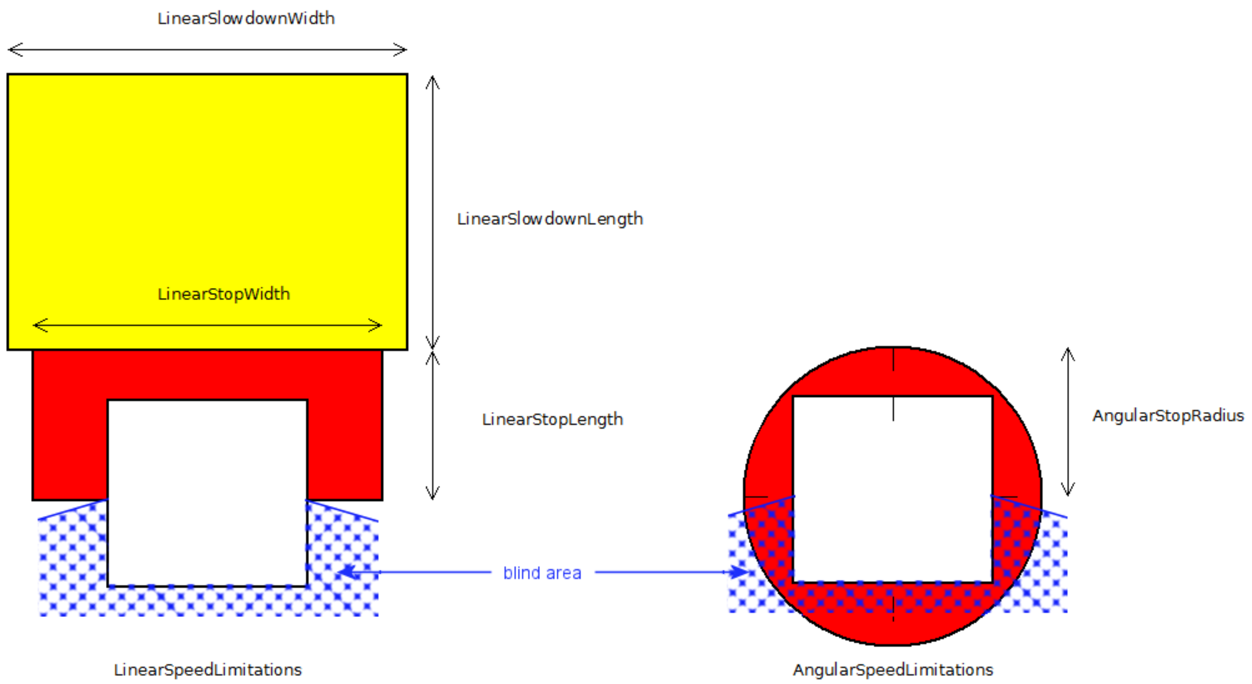


Figure 5: the collision avoidance settings (stop zones and simplified blind area)

The collision avoidance is situated in low level algorithms in PURE and observes the parameters "angular stop radius" all around the robot and "linear stop length/width" on the front side. There is also a linear slowdown zone in front of the robot. As noted, the detection of obstacles is not possible on the rear side of the robot (blind area) but the robot does not move backwards at any time. The collision avoidance relies on a single plane of the laser scanner about 26 cm above floor. All obstacles below or above this plane cannot be detected because the additional sensors are not active.

3.5.3.1 Results of collision avoidance

- Person/object within angular stop radius: the robot must stop immediately when there is something within the circular area formed by the diagonal dimensions (robot corner to corner) plus e.g. 5cm safety margin. This means that on the corners there is only 5cm margin, on front and side because of the geometrical situation it leads to around 15cm margin. This angular stop area prevents any rotation of the robot if there is an object detected to be in it. ☑
- Person/object within linear stop area: the robot must stop immediately when there is something within the rectangular area formed by the robot dimensions plus e.g. 5cm safety margin. ☑
- The robot should slow down its movement when an object enters the linear slowdown area, already before it comes into the linear stop area. ☑
- Persons with feet within stop area but legs still outside (to the robot's sides near the wheels or in front): this can lead to the robot running over the user's feet. Path-planning usually keeps a safe distance. ☑
- Tables or other furniture with legs farther apart than the minimum passage width and a plate outside the laser plane: this can lead to the robot colliding with the plate. Immovable objects can be marked in the planner map so that the path is planned around such objects. Undetectable movable objects or pets should not be allowed. ☑

3.5.4 Respecting of Personal Space

Many robot studies focus on reaching a certain goal in the environment while avoiding collisions on the way [6] which is not sufficient for the interaction of robots with humans. Therefore, several studies deal with the problem of how close a robot can go to a user to avoid frightening by intruding into personal space and provoking a retraction movement.

The so called "Personal Space", is the region formed by the distance that people prefer to keep away from others [9, 10]. Some exemplary figures can be found from Lambert [11]:

Range	Situation	Zone
0-15 cm	Lover or close friend touching	Intimate Zone
15-45 cm	Lover or close friends	Close Intimate Zone
45-120 cm	Conversation Between friends	Personal Zone

120-360 cm	Conversation to non-friends	Social Zone
more than 360 cm	Public Speech making	Public Zone

Table 1: Human-Human Personal Space Zones

Because of the touchscreen and speech input distances, the maximum operating distance often will remain limited to the Intimate and Personal Zones, needing the robot to achieve high acceptability to be "good friend" with the user.

4 Results by HMI function

The HMI is a combination of a touchscreen with audio output and user input by touch or speech. Note: USB audio is powered by robot, which leads to noise when robot is switched off. The touchscreen sometimes doesn't react to a finger press, the pen has to be used at least once before.

4.1 Menus

The structure of the menus should be clear to users from the big header line and the differently coloured background.
There is visible and audible feedback when an icon is touched.

- ➔ Too long pressing an icon should not pop up the circle but also activate the icon? Now it leaves the icon selected, but nothing happens.

Figure 6: main menu on HMI

- ➔ Shouldn't the internet connection status be shown in the group with microphone and audio on the left or in a separate place?

4.2 Speech input and output

All functions are also available via speech commands recognized by the system. In order for this to work, the user must perform a training session speaking some command texts and keep control over his/her voice. The user must stay within a range of about 1m to the RobuMATE and be able to speak clearly and slowly. It is usually not possible to give speech commands when the user is far away from the robot or behind the robot. The set of recognized commands will be restricted to a smaller list during the field trials to give more reliable results. ⍓
The speech output (English, German tested) produces very clear and understandable speech in a selectable (male or female) language. ☑

4.3 Settings and maintenance page

This page is OK, because only power and money status are for the end user. Maybe call it Status?

4.4 Mail sending page

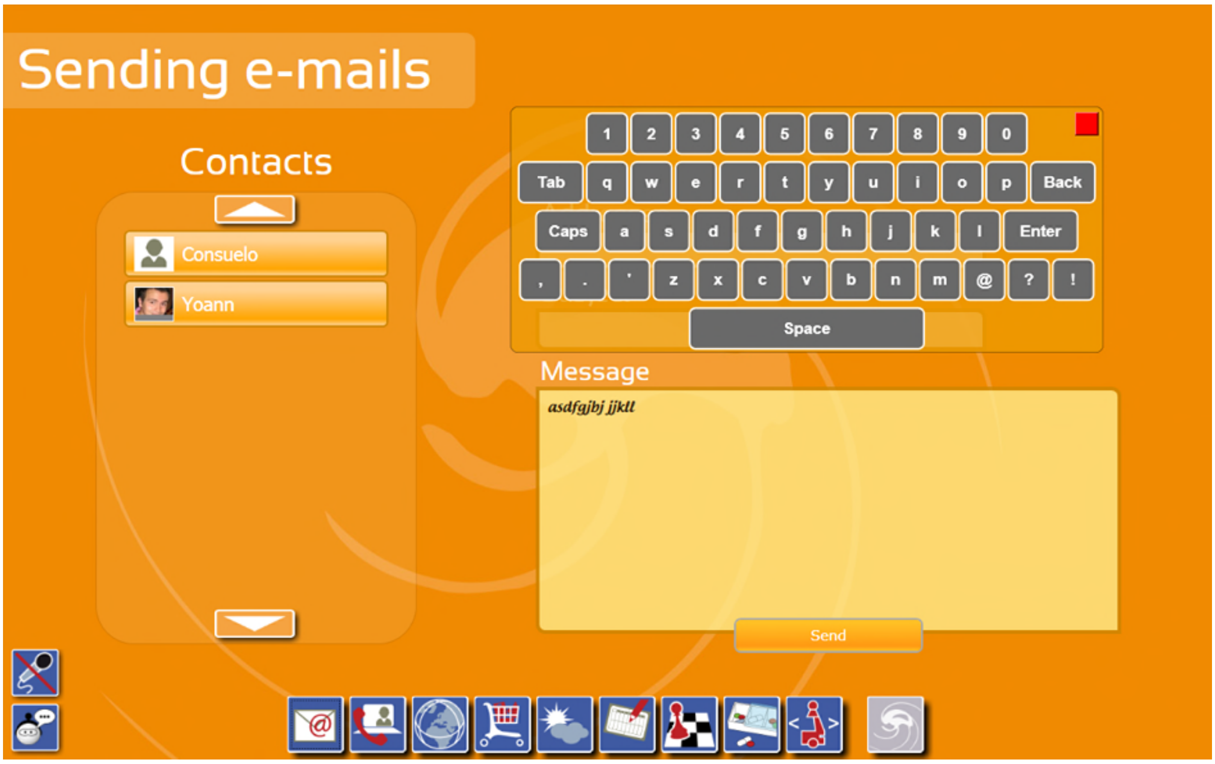


Figure 7: Mail menu

Font size of input fields too small/italic. Red close icon unclear. Names of contacts could be a bit bigger/bold or black. Send button too small font/contrast. ⍓

4.5 Videocalls page

Figure 8: Video call menu (contact names missing)

Font colour has low contrast and size of "hangup" button text too small.
Names of contacts were missing even if group names configured correctly – status was shown. This problem could be corrected by renaming of contact names (to same names) in Skype.

4.6 Web browser page

The layout and function seems OK. The text size in the browser will maybe have to be increased, so there should be a pre-configurable setting.

Figure 9: Browser menu

There should be a +- icon for instant zooming if font size is not appropriate.

4.7 *Shopping list management page*

Text in list slightly too small and italic. Clear button font too small.

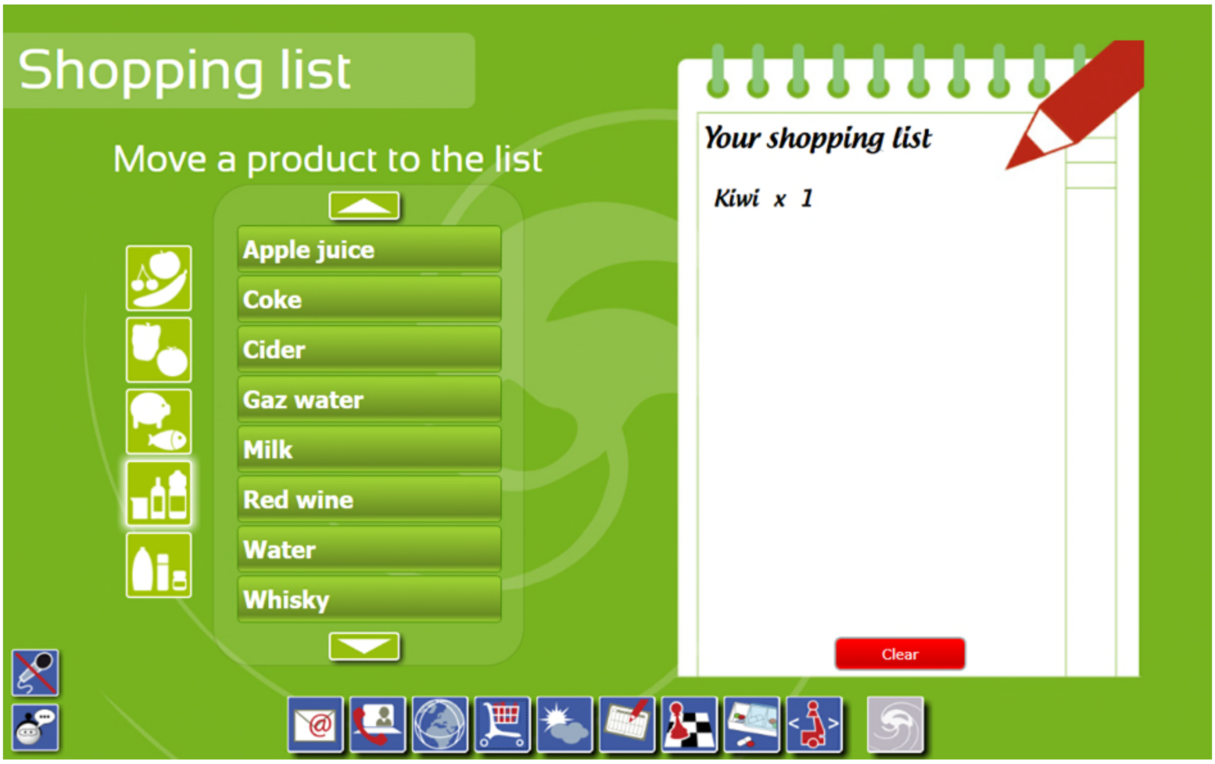


Figure 10: Shopping list

4.8 *Weather forecast page*

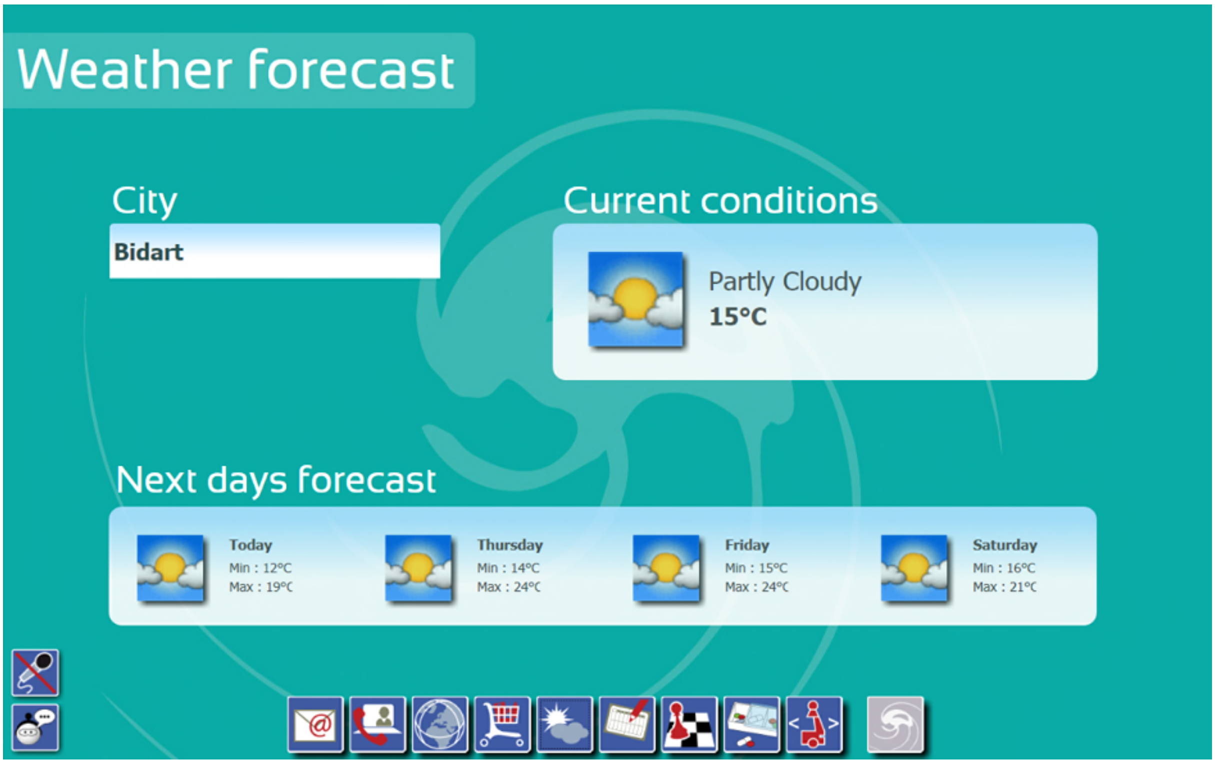


Figure 11: Weather forecast page

Next days forecast text is too small

4.9 *Agenda management page*

Text of event list, headers and date fields is too small. Contrast of dates is low (should be white?). Most users will not actively set appointments but just receive the notifications.

Figure 12: Agenda management page

Selecting the clock sets time with a popup sliding in.

4.10 Flash games page

Many elements are very small but now at least games are basically playable for skilled users.

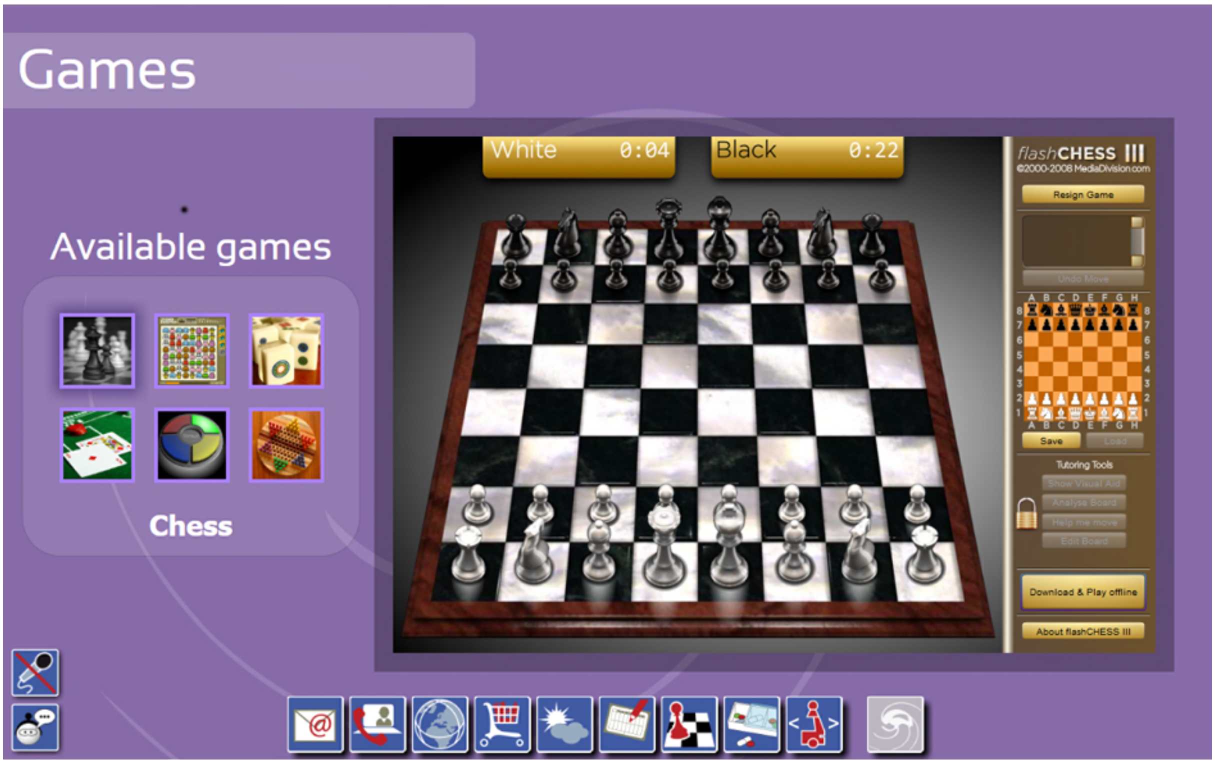


Figure 13: Game menu

4.11 Medical treatment management page

Font size/contrast too small. Background colour should be different to other menus.

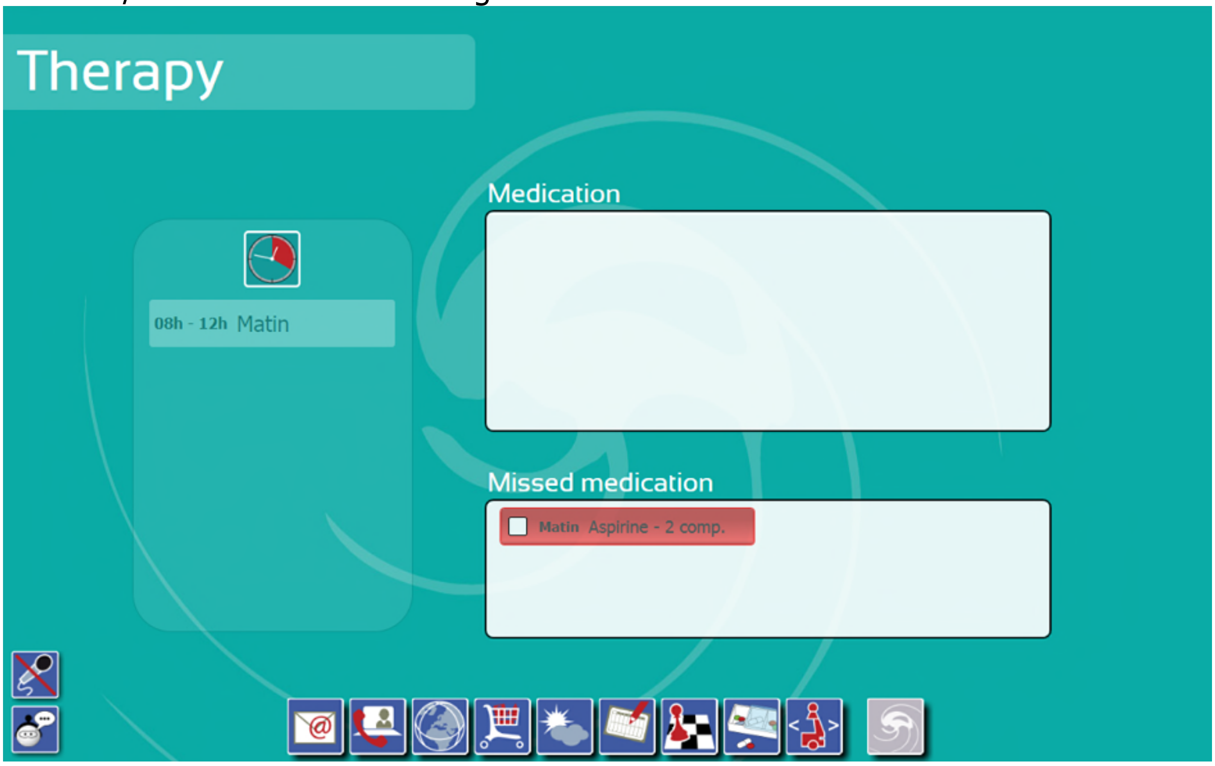


Figure 14: Medical treatment reminders

French name for time of day seems to come from the French Google document used. It seems that the information, which medication has already been taken, is lost at a restart of the HMI. Assuming that the HMI need not be restarted this poses no problem. Maybe it would be a good idea to store the intake times (or misses) for the doctor?

4.12 Robot control page

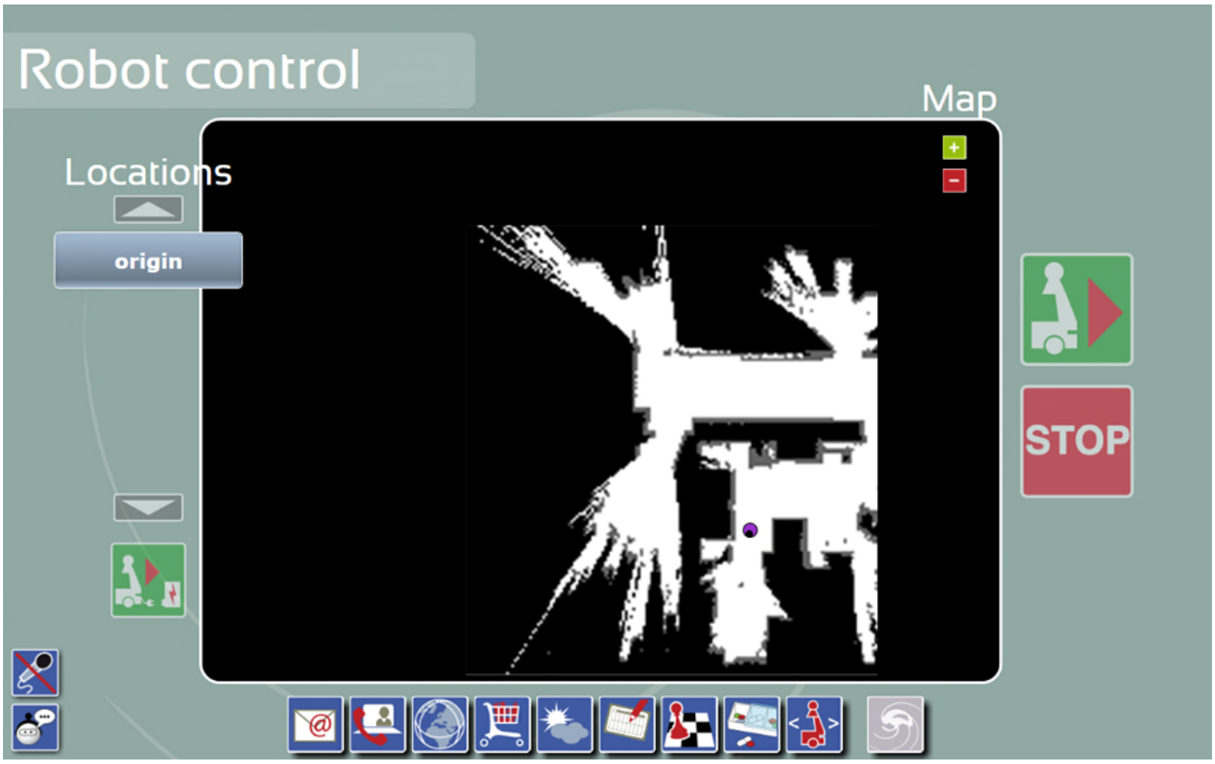


Figure 15: robot control page

There should be an autozoom for the start (map fit to window) or autopanning? Some danger that user might not know how to select correct zoom/pan. +- icons too close and small. The user will mostly make use of the PoI buttons.

4.13 Carry case (basket)

Not yet available.

4.14 Lokarria

Connection via VPN is OK and camera, map and laser scan are visible. Remote control is working. All OK in FF4 and ie8, video was not available in Chrome12.
Note: seemingly the camera video is continuously streamed, without any indication to the user. This is both a privacy issue and a waste of bandwidth.
Further tests revealed big problems with bandwidth of Lokarria server at some time which caused the robot to become uncontrollable (even by manual remote control!).

- ➔ There has to be a more reliable remote control protocol implemented to avoid unclear control status in case of network or server problems.

4.15 Teleconference

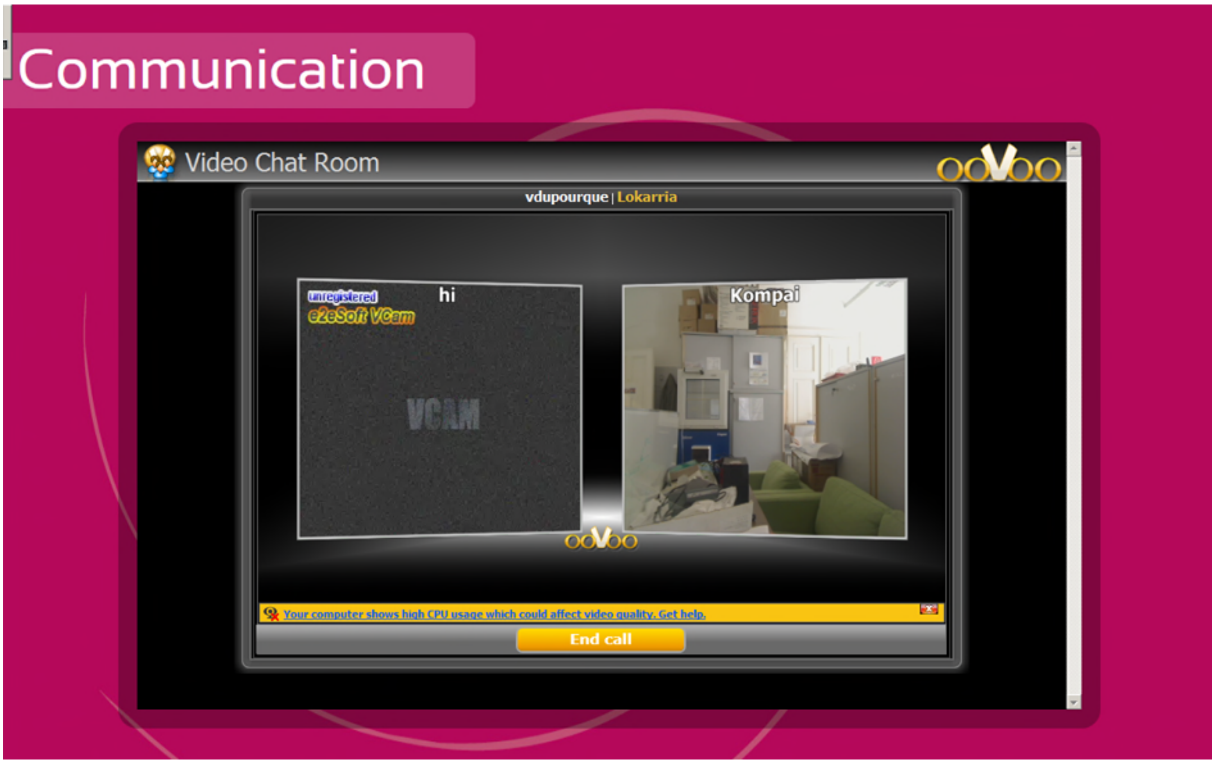


Figure 16: the ooVoo teleconference screen

The application takes a long time to come up (ooVoo was NOT running in background). There is also a warning of high CPU load. The audio information before and after the call seems appropriate, although there should be more time to react before the video/audio gets connected/the window comes up? 2nd call crashed with script error in HMI. Ending call from Lokarria: HMI didn't speak the end message and there is no possibility to leave the Communication page.

4.16 Call for Help

Not yet implemented (button)

5 Performance of specified functions

The following functionality according to deliverables D1.3 is implemented and is planned to be assessed during the fieldtests according to D7.1:

5.1 F1 Reminders (medicines, appointments …)

D7.1 evaluation: agenda with alarm function
Local version without need for Internet connection was not available. For the Internet based version see 4.11, 4.9
Summary: except some desired improvements in presentation (font size) OK

5.2 F2 Go to the docking station when battery level is low

D7.1 evaluation: automatic docking to the charger
Docking station was not available for testing

5.3 F3 Skype, with only 2 or 3 contacts

D7.1 evaluation: video-call, audio-call
Available and tested, see 4.5
Summary: except some desired improvements in presentation (font size) OK

5.4 F4 Tele-consultation with doctors

D7.1 evaluation: blood pressure and bodyweight
UBIK not available, medical sensors not available, ooVoo tested, see 4.15

5.5 F5 Aid call (button)

D7.1 evaluation: emergency signal, remote controlling
Button not available for test. Remote controlling see 4.14, Lokarria not reliable yet.

5.6 F6 Navigation to PoI(Point of Interest)

D7.1 evaluation: reaching given locations in the house, obstacle detection and avoidance
See 3.1.3.3
Summary: except some reliability issues of localization OK. Currently not fit for unattended 24/7 operation.

5.7 F7 Some website access (weather, shopping list, agenda, games ...)

This is reported in 4.8, 4.7, 4.9, 4.10
Summary: except some desired improvements in presentation (font size) OK

5.8 F8 Speech recognition

D7.1 evaluation: control by voice commands, speech recognition and synthesis
See 4.2
Summary: for users able to pronounce well and for limited vocabulary OK as additional input modality

5.9 Additional D7.1 functionality

carrying small objects – basket not yet available for tests
e-mail ☑
weather forecast ☑
entertainment ☑
shopping list ☑

6 Results by scenario

Assessment of the scenarios mostly is a summary over the HMI functions provided in before chapter.
The goal of experiments according to D1.3 is to evaluate how robotics can improve:

- Doubt removing in case of needed help
  - Call for Help and connection to centre ☑
  - Remote site monitoring and driving ⍓

- Tele-consultation
  - Regular video calls – medical parameters available (parameters not available for test) ⍓
  - Remote medication list and reminder ☑
- Socialization, through enhanced communication capabilities
  - Phone calls, emails ☑

7 Report about development of advanced functions (ISIR)

7.1 Human detection system

The ISIR partner is involved in this development because this task is really important to increase the autonomous capabilities of the Kompaï ; to find automatically a subject being allows to remember him/her an appointment, the drug schedule (etc.) without an external human intervention.

That requires a localization of the user relative to the robot and using the embedded sensors. In this context, we have to evaluate the embedded sensor capabilities in order to detect and localize a person. In others words, our work has been focused on:

- o the hardware evaluation of the embedded sensors (or the robot) regarding the people localization task,
- o the development of software components realizing the people localization using these sensors,
- o the characterization of (the hardware and) software components in terms of :
  - ▪ concerning the people detection task : the correct positive detection/false alarms rates (or ROC curves or precision/recall curves),
  - ▪ concerning the people localization task : the accuracy of localization.

7.1.1 Evaluation of basic components: laser based detection, vision based detection, multi-sensor based detection.

We have developed different software modules in order to detect human and to test it on the RobuMATE platforms. We have focused our work on a laser and vision based detection. Some results described here have been published in [17], [18] and [19].

The proposed people detection system deals essentially with the complementarity of two sensors: the camera and the laser rangefinder (SICK). It is particularly exacerbated by the sensor configuration in the Kompaï. In [17,18], combining a vision based whole body detector and a laser based legs one, we can notice that the human-robot distance is an important issue. At close distances ($< 1{:}4m{:}$), only the laser based detector works indeed. It is due to the camera view-range: the floor (and the whole body) can be viewed in the image only between $2m{:}$ and $9m{:}$. At farther distances ($> 3m{:}$), the body detector is more reliable and the legs one works badly. It is because the probability that a laser ray intersects a leg decreases drastically farther than $3m$. At middle distances, a merging process is needed to exploit the redundancy of the detectors.

7.1.2 Detection Algorithm

Three detectors are employed: a laser based leg detector, a body detector and an upper-body detectors both based on vision. Using a grid based approach and Gaussian Mixture Models (GMM), their output probabilities are combined as illustrated in the Figure 17.

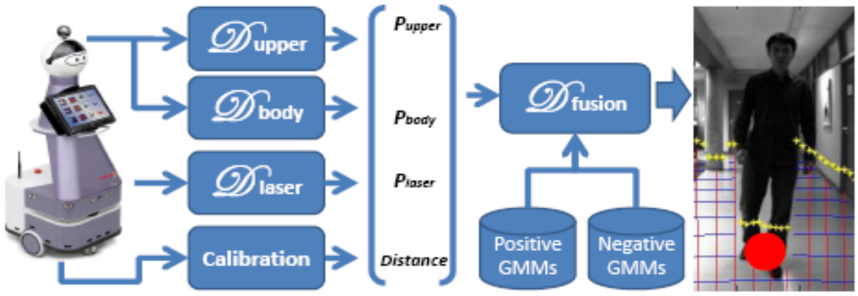
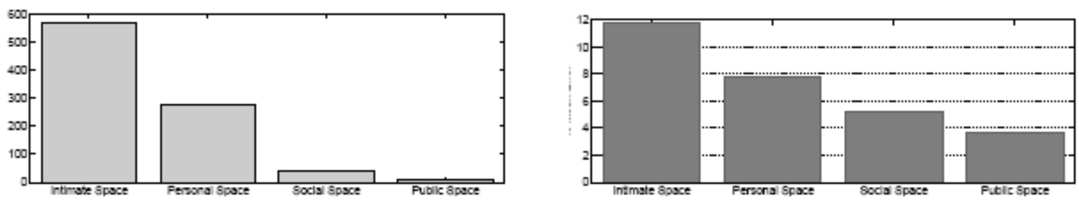


Figure 17 Synopsis of the developed human detection system.

Probability Grids. In order to do a consistent fusion of laser and camera data, we build for the two sensors, the same type of probabilistic grid. Our grids are based on a polar split of the space. The cells have different sizes with respect to the distance from the robot. Each cell is identified by its polar coordinates. A similar grid is defined for the camera on the floor according to the same equation in distance, but with a smaller angular range (according to the field of view of the camera). As we can see in the figure 18.a, the grid is more dense close to the robot (where we need a more accurate position estimation). In the Personal Space (between 0*:*45*m:* and 1*:*2*m:*), the relative mean error in distance due to our space sampling (Figure 18.b) is quite similar as the results obtained by Oskoei *et al* [8] (see too the section 3.5.4). In the same way, they have recently presented a work on the evaluation of the accuracy performance of a state-of-art Autonomous Proxemics System to keep an acceptable Human-Robot proxemics (HRP) distance during interaction with a human. This experiment was conducted with two subjects in the University of Hertfordshire "Robot House". Their analysis of the relative error means (approximately around 10%) between the desired and the obtained HRP distances, lead them to conclude that the proposed system works reliably.



(a) Density of cells (in number of cells/m^2) (b) Mean relative error (%) in distance

Figure 18 Grid statistics related to proxemics ([9] and section 3.5.4).

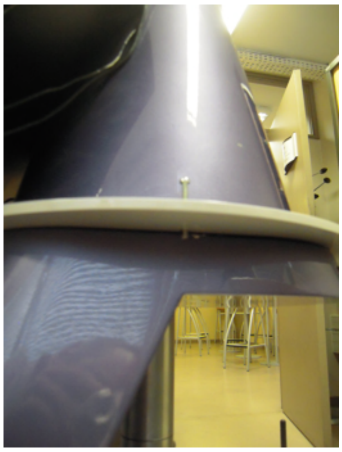
Detectors. Each detector is learned using Real Adaboost. The laser features [20] are inspired from previous works. In the two vision based detectors, two types of features are employed: Haar-Like (Haar-like features or Haar features) and HoG (Histogram of Oriented Gradients). These two features are frequently used in the domain of object detection and recognition. It has been proved the combination of the two types of features produces a more efficient detection system [21,22]. Haar-like features are derived from the wavelet decomposition (using Haar wavelets). They provide information about the gray-level distribution between two adjacent regions. Their outputs characterize the contrasted regions in the sub-image. The histogram of oriented gradients is a histogram of neighbourhood pixels according to their gradient orientation and weighted by their gradient magnitude. Subdivided and head-tail connected, HoG features [23,24] are particularly adapted to people detection: they provide compact and discriminative information on the contours (essentially on the body shape).

Grid Fusion. The merging process is composed of two steps. Firstly, the geometric relation between the camera and the laser scanner is estimated in order to match the two grids. The position and the orientation of the camera related to the floor is estimated with a test pattern (a known planar checkerboard) and using the Bouguet's calibration toolbox [25]. The geometric relation between the two sensors has been obtained following a calibration method proposed by Couverture *et al.*[26]. For the second step, as proposed by Premebida *et al.* [27,28], Gaussian Mixture Models are learned in a vectorial space grouping the outputs of the three detectors. To take explicitly account of the human-robot distance, we add it as another dimension of the vectorial space. The likelihoods with both positive and negative GMMs are computed; a log operator is then applied. A score is given by the difference between the positive and negative log-likelihoods. Applying a threshold to this score, we can estimate if there is a person in the cell.

7.1.3 Hardware evaluation and integration

On the Kompaï platform, the proposed pan-tilt camera has no position encoders. Therefore, the torso of the robot can be manually rotated but no angular position is available. In order to stabilize the geometrical relation between the camera and the laser, and realize the first experiments with the robot, we fix mechanically the torso and replace the pan-tilt camera with another static one on the head of the robot.

static camera



mechanical fixation of the torse

Figure 19 Hardware improvements.

In the future developments, we propose to replace it definitively with an advanced Pan-Tilt camera like the Sony EVI-D70 (or its Robosoft's version : the pgCAM). Currently, we are testing this new solution.

7.1.4 Software evaluation and integration.

Microsoft Robotics Dev Studio (MSDS) and Robubox cannot provide simultaneous camera and laser frames. So we have developed an external software that communicates with the different software components of the Kompaï using UDP communication protocols. Services were added to Robubox in order to compute the information provided by our People Detection Algorithm (see Fig 20).

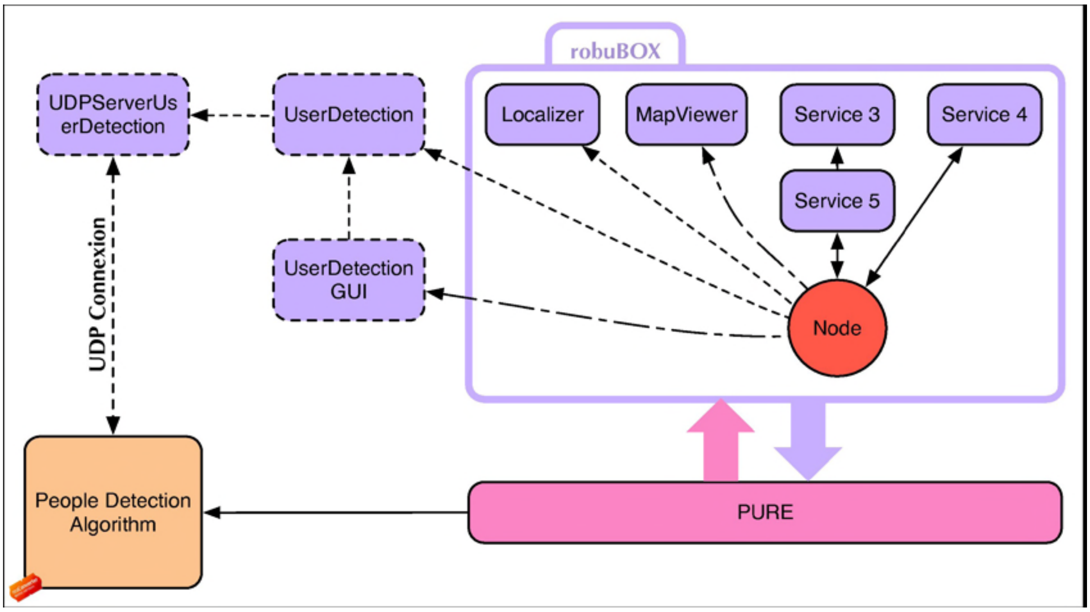


Figure 20 Developed software architecture.

The *UDPServerUserDetection* service is connected with the people detection algorithm. The *UserDetection* service subscribes to the *USPServerUserDetection* in order to receive the coordinates of people and *Localizer* receives the coordinates of robot. The *UserDetectionGUI* subscribes to the *UserDetection* in order to display people on the map (cf. Fig 21).

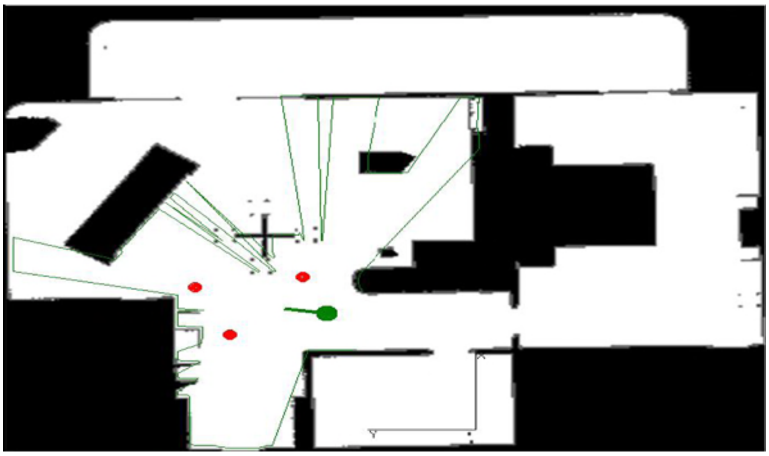


Figure 21 Map with the robot (in green) and the detected people (in red).

7.1.5 Current results.

In this section, we present the experimental protocol and the obtained results.

Experimental protocol. The experiments have been conducted in the ISIR's laboratory moving the robot in three different environments. During the experiments, the robot has been remotely controlled in order to test the algorithm performances in real and natural situations and in a not structured environment. We have asked participants (one or two persons at a time) to walk naturally in front of the robot. We have conducted these experiments without using the pan-tilt head mobility (both its angles are fixed and the camera looks straight ahead the robot). These experiments replicate the scenario when a domestic robot is proceeding any task and suddenly a person appears in its field of view.

Subject	Height(m)	Gender	Origin	Clothes*
1	1.56	F	Asia	LS
2	1.66	F	Europe	SS + TP
3	1.69	M	Europe	LS + TP
4	1.70	F	Asia	SS
5	1.70	M	Europe	LS
6	1.70	F	Europe	SS
7	1.73	M	Europe	LS
8	1.73	M	Asia	LS + TP
9	1.76	M	Asia	LS + TP
10	1.78	M	Colombia	LS
11	1.78	M	Europe	LS
12	1.78	M	Half-cast	LS
13	1.80	M	Europe	LS
14	1.86	M	Europe	LS
15	1.98	M	Europe	LS

*(SS: snug slacks, LS: large slacks, TP: textured pullover)

Table I : characteristics of the subjects

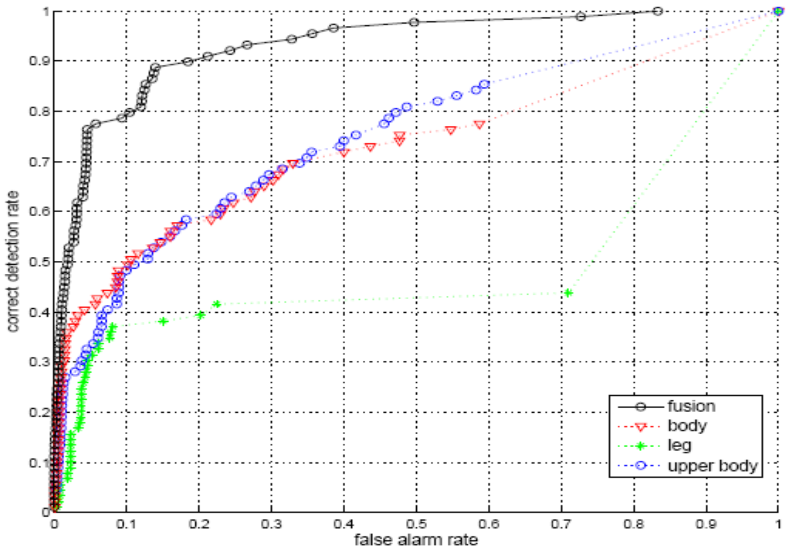
We have selected between the students of our laboratory, fifteen persons (cf. Table I) of different heights, weights, gender, origins and dressed with different clothes (with large and snug slacks, with self-coloured and striped t-shirt, etc.). We have collected 271 data (image+laser frame): 131 with one person and 140 with two persons. They represent 411 potential observations of a human in the environment by the robot. The distribution of these observations related to distance ranges is given in Table II.

distance range (m)	observations
[0-1.2]	49
[1.2-3.5]	116
[3.5-12]	246

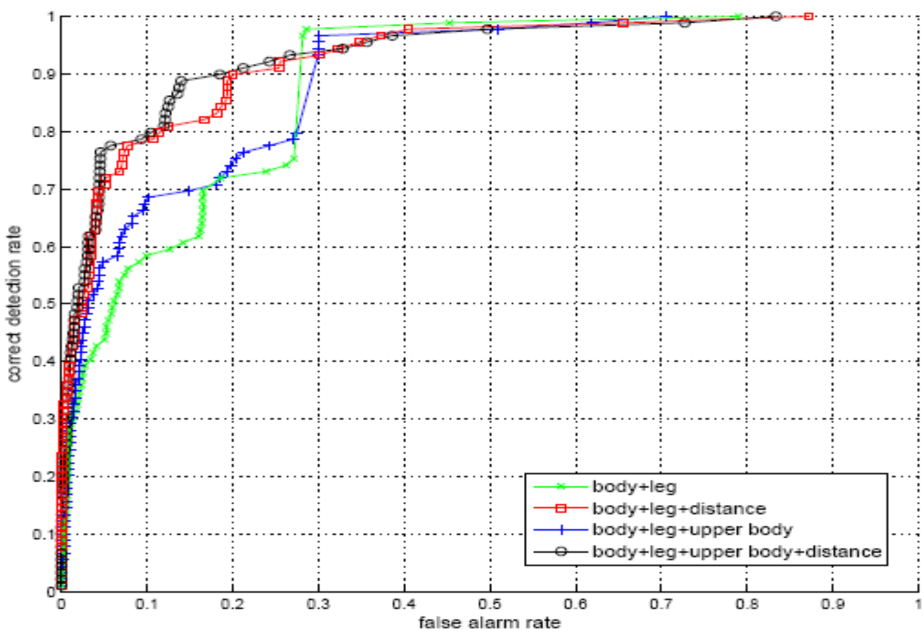
Table II : Distribution of the human observations

Figure 22.a shows the ROC curves obtained from the three detectors and the GMMs based fusion. Merging the laser based detector and the vision based detectors works well as expected: the fusion's curve rises above the others. The relative weakness of the leg detector is partially due to the non-homogeneous distribution of the data (cf. Table II): there are less human observations close to the robot (where the laser based detector works well). Another observation concerns the results of the vision based detectors: they are similar. They are clearly redundancy with this sensor configuration. It is confirmed in the Figure 22.b. This figure allows to compare between four detectors based on different GMMs fusion strategies: *D*1 based on 4-

dimensional space $(r, P_{body}, P_{upper\text{-}body}, P_{leg})^T$, D_2 without distance information $(P_{body}, P_{upper\text{-}body}, P_{leg})^T$, D_3 with $(P_{body}, P_{leg})^T$, and D_4 with $(r, P_{body}, P_{leg})^T$.



(a) Comparison with the 3 detectors



(b) Comparison with different fusion process

Figure 22 ROC curves.

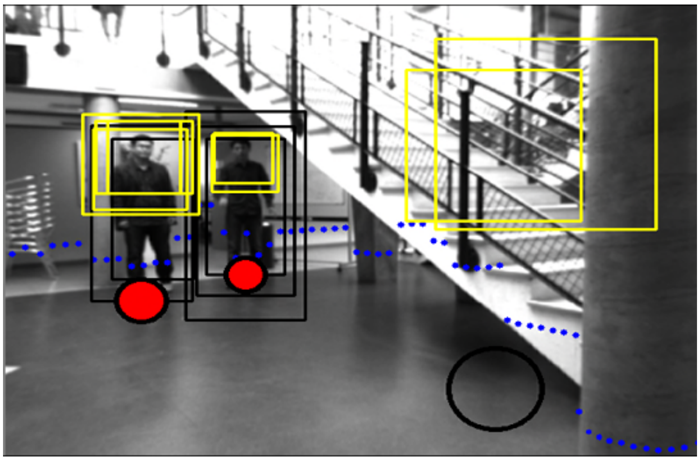
This figure shows that the performances can be greatly improved by considering explicitly the human-robot distance in the detection system. We can also observe that the inclusion of the upper-body detector in the fusion process improves weakly the performances. But it will useful to detect sited persons.

Some obtained results are given in Figure 23. The detections from body/upper body/laser detectors are marked on the image by empty black rectangles, yellow squares and white points respectively. The GMMs based fusion results from D_1 is marked as a red filled region near the person's feet. The black circle illustrates the obtained detections from *D*2. All detector are adjusted at similar precision to make comparable their detections. The two subjects in Figure 23.a are missed by the laser detector, but successfully detected by both fusion strategies. The upper-body detector generates two false detections near the column which is accepted by *D*2, but rejected by *D*1 who takes the distance information into account. At this distance, a laser confirmation would be expected. We would like also to point out that multiple vision detections on the same subject could be considered as filtered by the fusion process.

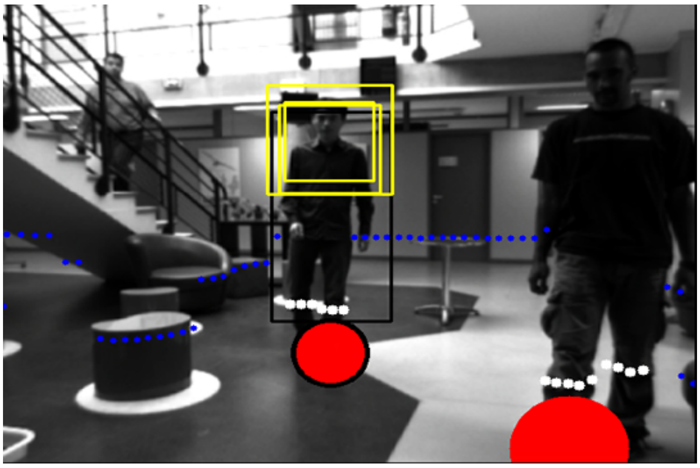
In Figure 23.b, the person in front is missed by *D*2 as only *D*laser has a significant output. Because the laser detector has a high precision when the distance is small, *D*1 takes advantage from the distance information and accepted the laser detector's report. We remark that the person on the stairs is not detected by any detector. This is because our grid is constructed on the ground and we assume that the floor is flat. This hypothesis is reasonable because the Kompaï robot is designed to work at locations with no stairs higher than 1.5*cm*. Furthermore, compared to an exhaustive sub-window extraction, we can extremely reduce the number of windows to be detected and achieve a real-time system.

The third image (Figure 23.c) shows a false detection caused by a vertical potted plant. This error is very typical for vision based detectors. This detection is accepted by *D*1 without the laser based detector's confirmation, because the vision based detectors are assumed to work better at far distances. In HRI applications, these types of error are relatively acceptable: either a long distance detection could be not considered by the robot (without a explicit audio or gestural call from the potential user) or a long distance false alarm could be erased when the robot moves closer. The body detector failed to detect the subject in this image. The detection of people with textured clothes is still an open problem in the computer vision domain. But the probabilities of person presence in that cell, given by the vision base detectors, even if they are weak, are enough in this case for the fusion detector to valid the detection.

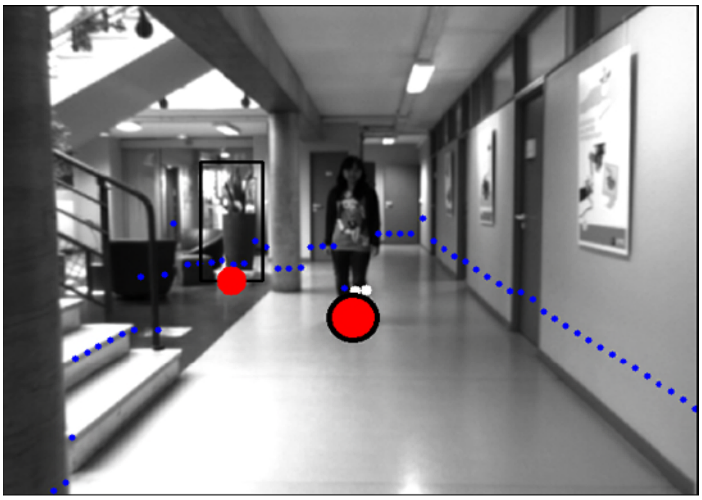
The current detection system is based on a statistical learning; from samples of people and not people. But if it is relatively easy to collect several samples of people, defining what is a non-person is more difficult. Usually we collect a large set of data samples which are not containing people. And we hold on the generalization propriety of the learning machine to determine the most powerful decision boundary. But in fact, the detector is often better in some environments and less in others, depending on whether the negative database matches better with the first ones. The developed system (in two steps) can theoretically build automatically the negative database and adapt it relating the environment where the robot is deploying. It could be made when the map of the environment is realized by the robot (via the Karto's software SLAM). Thus our system should be able to learn the environment in which it operates, and enable it to detect people with an optimal performance.



(a)



(b)



(c)

Figure 23 Examples of detection results (Body: black rectangular; Upper-body: yellow square; Leg: white points; Fusion with distance: red disk; Fusion without distance: black circle)

Currently, we are developing this last improvement and extending our database and our method for including sited or partially occluded people.

7.2 Verbal and Non-verbal communication

The objective of this research contribution is to address the Human Robot Interaction (HRI) components of Kompaï and more precisely cognitive and memory assistances. The key issues identified by ISIR partner for the DOMEO project are the following ones:

- Set-up of laboratory evaluation scenarios and metrics
- Evaluation of basic components: speech recognition, speech synthesis, dialog management
- Proposition and development of adapted components for the improvement of Kompaï
- Development of high-level functions for robust interactions

7.2.1 Set-up of laboratory test

Works done within the WP4 require the development of basic scenarios that can be played in laboratories before the deployment in hospitals and homes' patients.
We proposed to follow a methodology usually used in early stages of HRI systems, which is the Wizard-of-Oz (WoZ) mode: a robot is remotely controlled and the tests are recorded (audio/video) and further analysed (annotations). In addition, we designed questionnaires for end-users.
The WoZ methodology allows us to refine and to understand the behaviours of both human and RobMate during the scenario.

The set-up scenario is the following:

1. The robot moves towards the patient and then the robot introduces (verbal communication) briefly its role.
2. RobuMATE starts a dialogue by asking various questions: How are you going? What a nice weather today!...
3. RobuMATE proposes some services: play a video, explain robot's functionalities, or move in the room…
4. RobuMATE proposes to the user to go together to another place. (Various strategies can be employed: propose a coffee, take an object…)
5. Arriving to the pre-defined place, the human has to put an object on the top plate of RobuMATE
6. RobuMATE suggests to go back to the previous place

This scenario allows identifying several macro-behaviours: how to regulate the interaction (who speaks when)?

Evaluation of mobility with a human. Regarding the mobility, the comfort has been evaluated during phase 1 (human always at the same position and Kompaï is moving), phases 4 and 6 (both the human and the robot are moving), phase 5 (the robot is not moving and the human is doing an action requiring to move towards the robot). Following the WoZ methodology, a human is continuously and remotely controlling the robot and consequently the distance. At the end of the experiment, a questionnaire is proposed to the users. Experiments have been carried out with 22 subjects and results are reported in figure 24.

Question	very bad/ strongly disagree	bad/disagree	Good/agree	very good/strongly agree
How do you find the oral expression of the robot?	0	13.64	15	68.18
Are you satisfied with the oral comprehension of the robot?	4.76	9.52	80.95	4.76
Are you satisfied about the distance between you and the robot?	0	0	86.36	13.64
How do you find the movements of the robot?	0	9.09	86.36	4.55
Do you find the robot stimulating?	9.09	18.18	72.73	0
Are you interested of participating in other experiences with robots?	31.82	9.09	50	9.09

Figure 24 Distance evaluation

7.2.2 Evaluation of basic components: speech recognition, speech synthesis, dialog management.

The basic components of a dialog system are speech recognition and synthesis. Robosoft dedicated a speech solution based on Microsoft Robotics Dev Studio (MRDS) tools. Several dialog situations have been identified and implemented on Kompaï: Hear management (start/stop robot listening), General information (time and date), Shopping list, appointment, Wake up, Medical services, Robot's movements, E-mails.

A first experiment was done with the first version of the dialog system (in French):
11 users (elderly people) were asked to achieve some functions or tasks with the robot:

1 Ask for date and time
2 Ask the content of the shopping list
3 Add something on the shopping list
4 Remove something from the shopping list
5 Request to wake up
6 Request the appointments of the day
7 Make an appointment with somebody
8 Ask for the next appointment with somebody

The test evaluates the words and the syntax used by elderly people to achieve these tasks. Consequently, a WoZ approach was employed. Experimental details are provided in [31]. Interestingly, only 44.5% of the sentences uttered by the users coincides exactly with those already implemented on the speech recognition system of RobuMATE. In addition, 42.1% of the uttered sentences contain words unknown by the robot (not present in the vocabulary of the speech engine).

The experimental results motivate us to enrich and adapt the vocabulary and the syntax of the speech recognition system.

Regarding the speech synthesis, we exploited the results of the WoZ experiment for the adaptation of both vocabulary and syntax sentences.

A dialog manager. The first trials have shown the importance for the design of a dialog manager for the HRI system developed in DOMEO at least in French by characterizing the end-users in terms of vocabulary and syntaxes employed and also behaviours.
However, in order to improve the robustness of the HRI system, we proposed a new approach beyond the state-of-the-art interactive systems. The basic idea it that elderly people may not have access to language or with difficulties, which reduce the performance of the speech recognition system. In addition, speech synthesis is not always understand by the end-users. Basically, providing a list of services only verbally usually increases cognitive loads.

With these points in mind, we proposed to use:

- Input signals: speech + tactile
- Output signals: speech + graphics

The architecture employed both fusion and fission of information in order to improve the robustness of the dialog manager as shown figure 18.

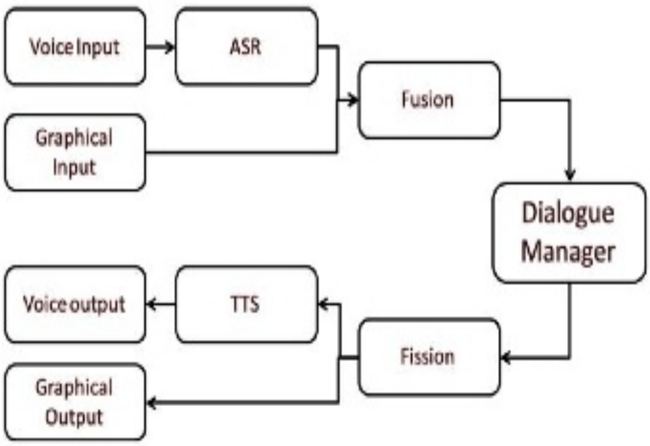


Figure 25 Multimodal approach using fusion and fission processes to combine speech, tactile and graphical signals

A key issue of this multimodal approach is how to associate images and speech.

Spoken words by the user or the robot are usually devoted to services (medical, appointments…). The images should be easily understandable by elderly people. For this purpose, we employed a methodology and images previously introduced by some authors [29,30]. The key idea is to evaluate and select pictures that will be more identified and associated to services. Details of the experiment are given in [31].

Figure 26 Example of the robot interface developed by Robosoft [31]

7.2.3 Development of high-level functions for robust interactions

From the first trials, engagement detection has been identified to be a social signal that can enhance the robustness of the HRI system. The basic idea is to add non-verbal information such as face detection, user movements.
Currently, a machine learning approach is developed for the fusion and the processing of multi-modal signals based on dynamic Bayesian networks.

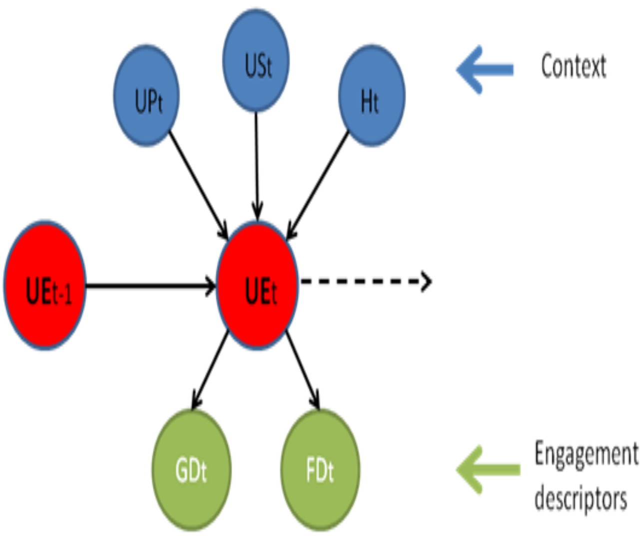


Figure 27 Engagement model

The model employs several information such as user position (developed at ISIR in collaboration with Robosoft), voice activity (speaker is speaking), history context (the user was engaged or not), head information (eye-contact estimation by both face detection and eyes detection).

Speaker detection based on visual features. We recently proposed a speaker detection system based only on lip movements for close interactions. The problem can be formulated as the detection of the speaking partner during interactions. This task is important since in the situation described figure 28 the robot is not able to focus its attention on the right partner.

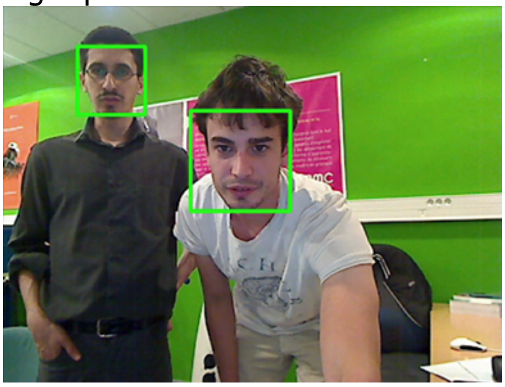


Figure 28 Engagement formulation: example of two partners

To deal with such situations, we proposed the following steps:

- Face detection: How many faces?
- Face tracking: to be able to track the movements of the potential partners
- Mouth detection
- Mouth tracking
- Detection of lips movements

In order to optimize the processing and to make it more robust, we decided to employ a similar strategy for all the detection (Haar classifier) and the tracking (particle filter) processes.

Object detection: Face detection is done by using the standard Viola-Jones detector that is based on Haar-like features and boosted classifier (cascade). For DOMEO project, we employed classifiers previously trained and available on OpenCV. One should note that improvements could be achieved by a specific training phase. Regarding the mouth detection, we followed a similar approach by using mouth classifiers previously trained.
For each face, we compute a color histogram allowing identifying each speaker by a specific label. One should note that this is not an explicit face recognition system since no off-line training on the identities has been done. However, the system is an on-line face discrimination system.

Object tracking: Object tracking is introduced in the process in order to reduce the computational costs by avoiding frame-by-frame detection as well as following all the potential partners (each one has been artificially identified during the object detection phase). Object tracking is a difficult task and several methods have been proposed. Here, we employed a state-of-the-art approach based on particle filter.
The tracking process is firstly initialized by the detection phase (histogram). The key idea of the approach is to anneal particles for computing a sampled representation of the probability distribution of objects. By updating these probabilities and the

sampling, tracking approaches based on particle filtering has been shown to be efficient.

Lips movements: Once the region of the mouth is detected, we estimate a colour histogram of this region. When a partner is speaking variations of this histogram should be observed. Comparisons between close and open mouths allow detecting the speaker as shown in figure 29.

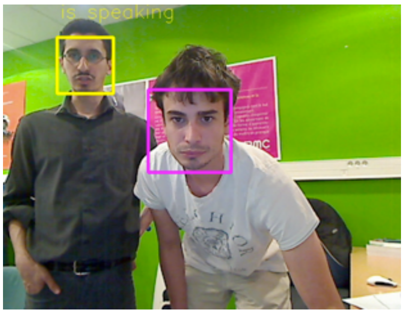


Figure 29 Speaker detection based on lips movements

8 Conclusions

The pre-final prototype tested under laboratory conditions performed well for most of the functions. For a reliable 24/7 operation in the end users' home still there are some problems with reliability of localisation and path planning in complex environments, the not yet available docking station and some usability issues that must be taken care of before and during the user trials. The work in WP4 and the deliverables D4.1 and D4.2 will keep track of the improvements made in the final prototype for the user tests and the advanced functionality developed.

9 Literature

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