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IntelliTable: Inclusively-designed furniture with robotic capabilities

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Abstract. IntelliTable is a new proof-of-principle assistive technology system with robotic capabilities in the form of an elegant universal cantilever table able to move around by itself, or under user control. We describe the design and current capabilities of the table and the human-centered design methodology used in its development and initial evaluation. The IntelliTable study has delivered robotic platform programmed by a smartphone that can navigate around a typical home or care environment, avoiding obstacles, and positioning itself at the user's command. It can also be configured to navigate itself to pre-ordained places positions within an environment using ceiling tracking, responsive optical guidance and object-based sonar navigation.

Keywords. Assistive robot, overbed table, human-centered design, intelligent furniture.

1. Introduction

Future homes will integrate robotic technology into many everyday devices and objects; expanding their functionality, ease-of-use, and customizability. An important class of objects will be items of furniture that have embedded intelligence and actuation capabilities; this 'intelligent furniture' will be useful to everyone but particularly to people with limited mobility.

The creation of intelligent furniture will bring state-of-the-art robotic technologies out of the lab and into the domestic and healthcare environments. In this project we developed and performed some initial user tests with a proof-of-principle exemplar of this new class of device. The IntelliTable is a contemporary-design universal cantilever table able to move around by itself, or under user control, in an indoor environment. The table is designed to support people to live more independent and productive lives, particularly as they grow older. Developed through an academia-industry collaboration involving the University of Sheffield and a leading UK design company, IntelliTable sought to emphasize high-quality inclusive design, safe and intuitive functionality, affordability and environmental sustainability.

The IntelliTable is aimed at both the healthcare industry and domestic home care market, we envisage this as a device that could reduce some of the pressures on

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nursing staff and carers in supporting people with limited mobility, at the same time giving users greater control over activities such as working and eating from a bed or chair.

2. Methods

The study process was split into three phases each with specific tasks and approaches:

- *Research & Scoping.* Here we surveyed the various issues and opportunities, examined the existing state-of-the-art of related devices, and agreed an overall approach and design brief.
- *Conceptualization & Visualization.* This involved creating an outline design & technology strategy that was visualized with various sketches and simple models, which were analyzed & discussed and agreed as the best approach to adopt for the project.
- *Design development.* This iterative process involved creating specific design models, functioning and non-functioning for evaluation and user-testing with repeated rounds of stakeholder engagement. The design process involved creating a number of iterations for both the industrial design, electronics and software, testing for functionality, ergonomics, navigation and manufacturability with various working and non-working 'how it works' and 'how it looks' prototypes.

It is central to any good design process to involve the intended users in specifying the design, and for feedback on subsequent iterations. It is also now standard practice to involve likely users in an advisory way throughout a project. The argument is that most often innovators and inventors do not have the direct experiences that can help identify what is important to the beneficiaries/users. In the domain of health research this has been labeled as patient and public involvement (PPI)[1]. Formal research methods were well beyond the resources available to the IntelliTable project. Hence public and patient involvement or co-incidental opportunities were employed during these earliest stages, beginning as soon as an initial concept had been conceived.

Initial user engagement meetings comprised an explanation that a University project with a business partner was underway to develop a robotic table and that there was need some feedback on the idea and to identify any issues the individuals were aware of, especially potential problems. The volunteers sequentially discussed what their experience with wheeled tables was; what issues/problems they had come across; and their thoughts about the initial design concept represented by a scale model. Three professional stakeholders, engaged in providing support or therapy for older people and 8 potential end-users, aged 50-85 were consulted for their opinions. Feedback was compiled into a summary and relayed to the developers via a project meeting.

The launch event of a new collaborative project between the University of Sheffield and the Occupational Therapy Department of Sheffield Teaching Hospitals offered the opportunity for further feedback to be elicited from the stakeholder groups: 6-8 occupational therapists, 2-3 ex-patients of the Occupational Therapy (OT) service (all with remaining functional impairment) and 4-6 academics all new to IntelliTable. This occurred in half-hour round table discussions with each of two groups and each including mixed stakeholder representation. The discussions comprised an introductory presentation about the project and IntelliTable. More detailed presentation of the prototype and its imagined uses followed, using illustrative materials such as those shown in figure 1, during which questions, comments and discussion was encouraged.

over-bed kitchen eating stability

Figure 1. Example materials developed for user-testing.

3. Results

3.1. Identified related solutions

A survey of the literature identified a number of related approaches none of which had resulted in a commercial device but that provided some evidence of the potential utility of the "intelligent furniture" approach.

- [2] presents the idea for modular robots as building blocks for furniture that moves and re-configures depending on the user's preferences.
- [3] describes ComforTABLE, a networked system of three intelligent components intended to intelligently support the physical organization of the immediate environment (the headboard, overhead display and side-table). The side table can raise, lower and rotate as well as moving between three designated locations within the house.
- [4] presents a prototype robot table, the PEIS Table, that navigates a domestic environment both globally (using a fuzzy grid-based occupancy map) and locally (using ultrasonic sensors for obstacle avoidance). A key feature is the use of an indoor GPS. A objective of the paper is to outline the goal of an ecology of cooperative of domestic robots installed alongside each other to perform complex tasks.
- [5] presents the concept and working prototype for an Assistive Robotic Table (ART), a suite of networked robotic components that combines and reconfigures the typical home nightstand and over-the-bed hospital table. ART is part of the home+ concept which aims to increase the quality of life of both healthy individuals and persons with impaired mobility and cognitive functioning by intelligently supporting their interaction with their home environment as well as giving clinical populations more independence and allowing healthcare professionals to increase the quality of their interactions with their patients.

3.2. Summary of design outcomes

The IntelliTable study has delivered robotic platform programmed by a smartphone that can navigate around a typical home or care environment, avoiding obstacles, and positioning itself at the user's command. It can also be configured to navigate itself to pre-ordained places positions within an environment. It has both ceiling tracking responsive optical guidance and object-based sonar navigation, which works reasonably well in order to prove the concept. The table is able to come to the user when signaled, where it can be figured to meet user requirements, and then return to a base position when not in use.

3.3. Physical design

The IntelliTable prototype has fixed rear differential drive wheels and casters at the front so that it can turn on the spot around the pillar axis and drive forwards and backwards. The IntelliTable has a table-top with two actuated degrees of freedom (DOF), lift and roll, with manual adjustment of pitch by the user, with geometry appropriate for use over chairs and sofas, beds, and wheelchairs, as well as in the kitchen.

Figure 2. The look and "feel" of the Intellitable prototype.

3.4. Navigation

The IntelliTable navigation system is illustrated in Figure 3. For landmarks, we use engineer-installed "APRIL tags" (http://goo.gl/Zz45MA) as developed by the APRIL

Robotics Laboratory, University of Michigan. The landmarks are installed on the ceiling (i.e. horizontally and facing downwards) at a size of approximately 200mm square. The landmarks are monochrome (black & white) visual markers with a 36-bit payload used to identify the individual marker unambiguously and are acquired through a ceiling vision camera.

For use in navigation, landmarks have to be mapped into the robot's local space. Owing to the landmark configuration in world space, this mapping consists only of a normalization for the height of the tag above the camera, as well as minor corrections for errors in the camera mounting on the platform.

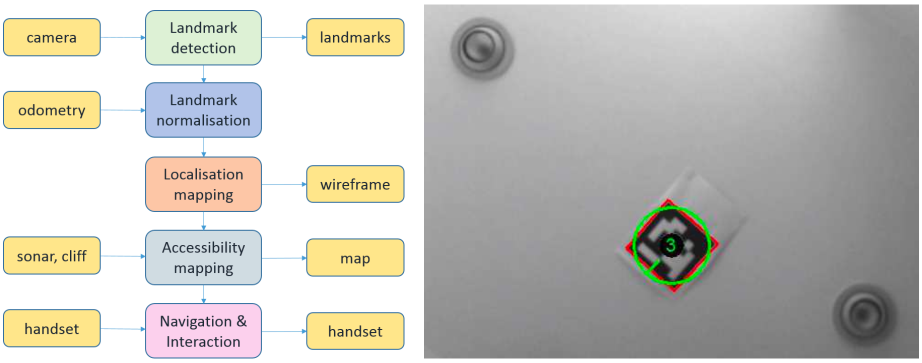

Figure 3. Left: Layered structure of "navigator" controller. Right: Landmark detection in an image from the ceiling camera. APRIL tag is identified, located, oriented.

The first stage of mapping is to localize the platform in the world. This is performed using an off-the-shelf and well-known algorithm "EKF SLAM". Our implementation is standard, except that we enforce approximate independence between landmark measurements by a heuristic that includes measurements only of landmarks that have not been seen for some fixed period of time. Once localization mapping is functioning, we implement "Accessibility Mapping" (where the robot can "access") as an independent layer built on top of the localization layer. These layers do not directly interact (there is no feedback from the accessibility layer to the localization layer). Accessibility mapping is implemented as a grid-based binary map. Grid cells are assumed inaccessible until the platform has entered them (in manual mode) and then they are marked as accessible.

Navigation is implemented using the Open Motion Planning Library (OMPL). On request, OMPL identifies a trajectory through pose (x, y, theta) space from the current robot pose to a stored robot pose. Once trajectory planning is complete, the robot follows the trajectory until the stored pose is reached. Obstructions detected using supplementary sensors (ultrasound or cliff sensors, in this implementation) during trajectory following trigger termination of navigation and vocal notification to the user. Interaction is implemented through message exchange with the handset app. Briefly, the handset app provides an interface to (a) store current robot pose as one of several "stored poses" and (b) commence navigation to one of the stored poses. The handset app also provides the engineer with a display of the current accessibility map, the current pose, and the stored poses, on request.

3.5. User testing

Notes made during user/stakeholder discussions were written up and shared with the developers. The feedback was overwhelming positive and encouraging from the two groups and no insurmountable barriers were suggested or identified in the discussions. Breaking the reported user testing feedback into topic areas identified three general themes in which the feedback primarily sits as shown in Table 1.

Table 1. General themes of feedback.

Theme	Topic	Feedback at event
Control & Accessibility	To be accessible to users with a variety of requirements, the table should be operable via a number of different methods.	Currently vocal, gesture, and remote control via a smart phone are planned.
	It was requested that the table should also be able to be switched on using methods other than a standard power switch, which can be difficult for some users to operate.	Current plans for this include a wristband and ultrasonic whistle.
Mechanical/Ergonomic issues	It was desired that the table should be able to integrate with existing assistive technology within the home.	
	It is desirable to have a single application that would control all technologies (for example both the table and home-management systems).	
	The compatibility with existing technology (e.g. phone types and other assistive technology) needs to be considered.	
Compatibility and Integration (with other AT and technologies)	There were concerns that different floor types may hinder operation, particularly deep pile carpets and rugs.	One solution is to have different wheel sizes, and to set the table up depending on the flooring in the home.
	Noted that for the table legs to fit under furniture, such as sofas, the casters would need to remain small regardless of other considerations.	

4. Discussion

Initial feedback indicates that the industrial design has been successful both aesthetically and functionally, The IntelliTable has been demonstrated to a number of potential end users, health care workers and occupational therapists who were engagingly positive about both its appearance and behavior. Most recently, the

IntelliTable has been exhibited at the London design museum as part of the “New Old” exhibition about design of enabling technologies for later life.

The further development of the IntelliTable is being taken forward by a University of S spin-out company. Figure 4 illustrates some further enhancements to the table and work-in-progress. Clearly, IntelliTable can be easily configured to have telepresence functions the addition of a tablet computer. Work is currently underway to enhance control functionality, from a tablet or smartphone interface, using speech and gesture control. Other improvements, currently under development, include pivoting legs will provide a horizontal work surface even when negotiating ramps and a proprietary omnidirectional drive system based around Swedish (mecanum) wheels that will allow the table to adjust its horizontal position relative to a user without executing a complex multi-point maneuver. This should significantly enhance the table’s usability. A more ambitious goal, illustrated in figure 4, is to add a lightweight robotic arm and hand to support fetch and carry functionality and to provide more specific assistance with tasks such as eating. The table-top could also be enhanced with interface technologies, such as embedded touch screens, or could be replace with therapeutic systems, such as delivery systems for physiotherapy.

The IntelliTable platform provides proof-of-principle for robotic furniture as a useful class of assistive technology device. Together with wearable monitoring systems and smart home sensors it is envisaged that a robot table, such as the IntelliTable could form part of a wider ecology of non-intrusive robotic systems that enhance independence and the ability to age-in-place, or, in as hospital environment, improve options for accessing a variety of activities that require an adjustable worksurface above the bed or chair.

5. Conclusions

The IntelliTable platform provides proof-of-principle for robotic furniture as a useful class of assistive technology device. The current paper demonstrates the feasibility of the device and the integration of mechanical and control technologies to create an assistive overbed table with some robotic functionality. The IntelliTable design is undergoing further revision and we expect to conduct a more systematic evaluation with end-users in the future.

Together with wearable monitoring systems and smart home sensors it is envisaged that a robot table, such as the IntelliTable could form part of a wider ecology of non-intrusive robotic systems that enhance independence and the ability to age-in-place, or, in as hospital environment, improve options for accessing a variety of activities that require an adjustable worksurface above the bed or chair. Our future work will also explore the integration of the IntelliTable within a wider care ecosystem.

Figure 4. Work underway will extend IntelliTable functionality through the addition of a table computer, omnidirectional drive system, and robot arm/hand.

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