Using CAN to retrofit houses for quadriplegic people

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This paper describes the B-Live® system targetted to automate house appliances for severely impaired people, in particular quadriplegic. This system has been developed at Micro I/O for enhancing the quality of life and the independence of its potential users. The envisaged application is the retrofitting of common dwellings.

The B-Live system is described and details on its software, hardware and CAN-based communications architecture are provided. A survey of the supported appliances and interfaces is presented as well as a description of the B-live configuration and operation procedures. The adequacy of the B-Live system to improve the autonomy of the envisaged users was informally evaluated by C5 and C6 patients at a demonstration house located in the CMRRC Rovisco Pais, a rehabilitation center near Aveiro, in Portugal. The conclusion is that the system has a short learning curve and can cope with the requirements of its potential users. The use of CAN in this application opens the possibility to include safety critical real-time systems in the B-Live system. This is the case of the monitoring of the ventilator used for quadriplegic people that require breath assistance.

Introduction

Quadriplegic people are severely disabled persons that became impaired due to several causes, namely accidents in pools, roads, riding horses and similar. In Portugal most of those persons are sent to their homes after a rehabilitation process carried on first at a normal hospital and, after, at a specialized rehabilitation center.

Due to their severe disability, quadriplegic persons are unlikely to be alone, thus requiring a permanent caregiver, at home. This task is normally performed by a close relative, usually mother or husband / wife.

The permanent and close co-habitation between patient and caregiver poses many severe social, psychological and economic problems.

First, caregivers have strong difficulties in carrying a normal life, either in social and professional terms. This has a strong impact either in theirs and in patient's psychological conditions.

Secondly, this limitation has a strong economical impact either for the family and for the social security because the caregiver is unable to perform professional activity and then must be supported by social funding.

When the caregiver is a relative older than the patient, a severe social problem will be created in the future when the caregiver dies or is no longer able to perform this task adequately.

Taking these issues into account, a joint project was launched involving Micro I/O, a spin-off company of the University of Aveiro, this University and CMRRC-RP (Centro de Medicina de Reabilitação da Região Centro – Rovisco Pais), a rehabilitation center responsible for the central region in Portugal. The idea was to develop a system able to support those patients offering them autonomy during a time interval of up to 4/5 hours in order to enable caregivers to perform a professional activity. A prototype of such a system was to be installed and tested at the CMRRC-RP facilities where a set of houses to prepare patients and caregivers to return to their homes after rehabilitation was available.

The idea to maintain elderly, impaired or disabled people living in the comfort of their homes has already been proposed in the literature [3]. The idea is to use an automation (domotic) system to assist those persons, helping them with their daily life tasks (open doors, close blinds, turn on/off lights, eat, etc.) and to monitor their health condition or life support systems (vital parameters, ventilators, etc.).

This paper presents the B-Live system putting some emphasis on the usage of CAN as its communication backbone. The choice of CAN comes from several factors including its ability to convey hard and soft real time traffic and the expertise available at the B-Live designers team.

The paper is organized in six additional sections. First, a short assessment of related systems is performed. After, a description of the B-Live operation is included. Then some architectural aspects of the system are presented. It is followed by a section where the CAN based protocols used in B-Live are described with some detail. Finally, in the last contents section, the assessment of the system with patients is briefly referred. A conclusions and work in progress section closes the paper.

Related systems

Several types of domotic systems can be found, depending on the applications: new or retrofitted houses, large buildings. The former are mainly used for illumination and entertainment. They are often centralized, proprietary and require point-to-point connections with specific interfaces that can only be easily adapted to houses during their construction phase. One example is the Lutron system [4].

The second type features similar characteristics but provides support to retrofit houses, by using power-line, e.g. X10 [5] or RF communications, e.g. [6].

The third type addresses the environmental control of large buildings (illumination, temperature, etc.). These systems are complex, allowing thousands of sensors and actuators simultaneously. The prices per node can be high. Examples are standard technologies such as EIB [7] and LonWorks [8].

The field known as Smart Houses [9, 10] emerged from the research activity in home automation [11] and home networking areas. It became important, within building automation, due to its application in Assistive Technologies. The concept of Health Smart Home (HSH) [12] has been driven by the social-oriented application of Smart Houses in assisting elderly and disabled people [13].

An overview of the research chalenges in HSHs can be found in [1].

The B-Live System Operation

The B-Live system was designed to retrofit common houses in order to be usable for severely impaired patients. This means that there are two kinds of users: the caregiver and the patient. The former wants to “command” the house as usually. The latter requires specific interfaces which must be adapted to its ability to manipulate devices. He/she requires also uncommon devices not needed by the caregiver and other people sharing the same dwelling.

The B-Live system keeps then the normal controls of the house, such as, e.g., switches, door openers, blinds commands. The system adds also at least an interface adequate for the impaired patient.

In order to command the house, a tetraplegic person has to rely in the abilities obtained during rehabilitation. In some cases patients are able to move the hands in a specific way and, although with difficulties, they are able to operate a mobile phone. In this case the B-Live system offers a menu in the mobile phone where the command can be selected by the user.

More severely impaired tetraplegic may just have small movements in the fingers. One of the solutions proposed in B-Live is a (almost) zero force push button installed in the wheelchair arm which triggers a voice menu transmitted by the sound system output of a solid state module. When hearing the wanted option, the patient can use the switch to select it.

For still more impaired persons that can just move the head, a mouth switch can be used to trigger the referred voice menu. Another solution is to use a mouth mouse [14] or a eye command such as the one named Magic Key [15] to command a menu displayed on a computer.

The B-Live System Architecture

The B-Live system was developed as a modular home automation system that will enable conventional homes to become HSHs. The motivation for its development comes from two factors: the specificities of this type of home automation systems and the inclusion of health support systems.

Concerning the former, one should consider that the targets are conventional houses, adapted when users have an accident leading to a disability, e.g. quadriplegic people. Conventional house systems are different from building automation, showing a reduced number of appliances and no need for subdivision and/or hierarchies. Therefore, appliances can share a common vision of every event concerning the system operation. This enables the enhancement of configurations, giving the user the power to adapt the house to its own requirements.

The second factor adds more restrictive requirements to the automation systems in order to support the application in just one system. The inclusion of health support systems, e.g., life monitoring (ventilators, cardiac monitoring, etc.) makes the system safety critical. Also, the severe impairments of the potential users poses demanding restrictions to conventional systems. For example, a close door operation becomes much more critical. So, dependability and real-time issues must be seriously considered.

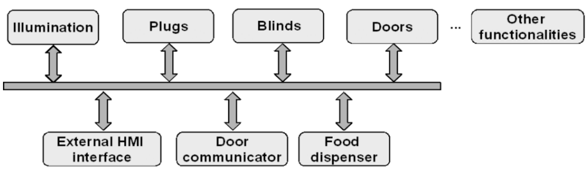

Figure 1: B-Live system architecture

The B-Live home automation system is modular. Each module can operate as an individual or together with the remaining modules. A CAN fieldbus connects all the modules, allowing the communication of information such as commands to operate the modules or status messages. The use of adequate Human-Machine Interfaces (HMIs) enables severely disabled users to operate home appliances. Fig. 1 represents the architecture of the B-Live system.

New functions can be introduced in the system by integrating specific purpose modules. These modules, however, do not interfere with the performance of the previous system. This is the main advantage of a modular architecture, as the system may evolve without compromising older functionalities. Currently, the system operates on the following home appliances: illumination (lamps and blinds), access (front and inside doors), outlets, door communicator and food dispenser (under development).

The B-Live system comprises several communication interfaces (Fig. 2), allowing the integration of applications running in other systems or devices. The interfaces can provide an interaction between the system and the user. For example, the B-Live system may communicate with HMIs through proper gateways, personal computers or special devices such as the IntegraMouse [14] or wheel chair interfaces.

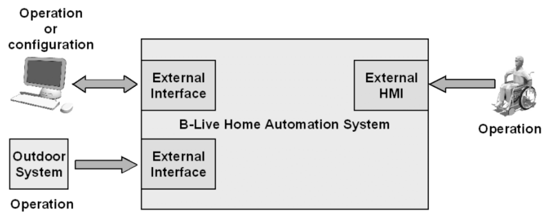

Figure 2: Interaction with the B-Live sytem

In what concerns communications, it should be noticed that the option for the CAN fieldbus arises from a set of properties and add-ons related with fault tolerant operation, real-time, cost and designer experience. In fact, the research team associated to the authors has done extensive studies of the use of CAN in real-time applications [16] and of adding fault-tolerance mechanisms [17]. More recently, extensive research has been carried on concerning the introduction of redundancy of CAN buses in safety critical real-time applications [18].

In what concerns the hardware architecture, the B-Live system is composed by modules with different functions but showing a common platform. Each module has two digital inputs for manual actuators (e.g. switches) and four digital outputs to operate external devices. Additionally, a module can also send/receive commands through the fieldbus. The use of a unified architecture facilitates the development and integration of new modules. A B-Live module is divided in two blocks (Fig. 3): the control board and the daughterboard.

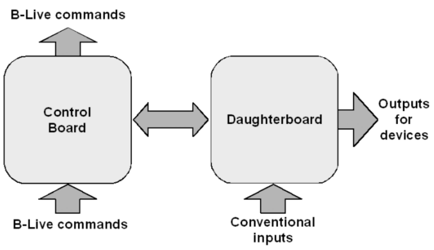

Figure 3: Hardware architecture of the B-Live modules

The former is responsible for tasks such as receiving and processing information sent by other B-Live modules, actuating locally (through the daughterboard) or sending instructions to the network. This board is based on a Microchip PIC18F2580 microcontroller. The daughter board drives local devices and provides communication between them and the control board. A B-Live module can be customized to any particular function (light switch, light driver, food dispenser control, etc.) by using an appropriate daughter board.

A more detailed discussion of an earlier version of the B-Live system architecture can be found in [2].

Using CAN in the B-Live system

As referred, the B-Live system uses CAN as the backbone for its internal communications. In order to enable the coexistence of hard real-time messages for life support systems and soft real-time messages as most of the ones used in the referred domotic applications, a solution based on a light version of the FTT-CAN protocol (not published yet) was adopted.

In this solution, the bus time is divided in windows with a fixed duration called Elementary Cycles (ECs). This window is divided into two other windows, one is dedicated for periodic traffic (synchronous window) and the other is reserved for the asynchronous traffic (asynchronous window).

Periodic, safety critical traffic in conveyed in the synchronous window, under the command of a special node, the Master, which transmits a trigger message at the beginning of each EC. This message contains the flags that instruct the nodes to transmit a message in a specific EC. The transmission of safety critical messages is out of the scope of this paper and will not be covered further.

The FTT-CAN protocol guarantees temporal isolation between the synchronous and asynchronous window, in order to protect safety critical messages from the interference of the others. This is done by encoding the length of the synchronous window in the trigger message and by adding special mechanisms at the node. Those mechanisms and the process to transmit a periodic message under the control of the master is performed by the FTT middleware which connects the application with the CAN device driver.

In the B-Live system, nodes that only transmit soft real-time traffic, as the ones currently used in the appliances described above, have a reduced version of the FTT middleware which is just used to prevent the node to violate the synchronous window limits. Such nodes use then just the asynchronous window to convey their messages. Arbitration in this window is done using the CAN native MAC.

Another innovative aspect of this middleware relatively to the standard FTT-CAN is the mechanism to operate without an FTT Master. The middleware is programmed to wait a specific time for a trigger message. If this message doesn’t occur, then the synchronous window protection is disabled and communication is done as if normal CAN was in operation.

Concerning the non safety critical communications of the B-Live system, a Publisher-Subscriber cooperation model (named BPSP – B-Live Publisher

Subscriber Protocol) was adopted to rule the operation of two device types: the Actuator (ACT, which includes switches, interfaces, commands, configurators, etc.) and the Actuated devices (DIAC which includes lights, doors, blinds, etc.).

The ACTs publish autonomously their associated events, for example, a state change, or their own state, after a request from an associated device. The DIACs publish their own state after a request from an associated device or change their state after an associated ACT has published a state change. Both ACTs and DIACs modify their configuration state after detecting an event from a special ACT, the CONF (Configurator).

BPSP defines also two special operations: configuration and binding. The configuration process is device-oriented or, in other words, operates over a single device at a time. This procedure associates a unique (system) identifier to the input (ACT device) or output (DIAC device) interface of a B-Live module.

All standard devices (ACTs and DIACs) are, by definition, subscribers of configurator devices. This means that, after having an identifier, they listen the bus in order to look for configuration messages from configurators.

The configurator device has the ability to publish configuration commands and can be implemented using a PC, a hand-held device, a mobile phone, an Internet device, etc. Because several configurators may coexist in the system, each one is uniquely identified.

The configuration procedure also involves the binding of devices where ACTs are virtually linked to DIAC or ACT devices. Moreover, all standard devices keep a list of the operation associated ACTs.

Devices communicate using the Publisher-Subscriber model, where ACTs and CONFs publish information subscribed by DIACs or others ACTs. Therefore, when a DIAC detects an event associated with one registered publisher, it operates accordingly, e.g., changing its own state.

As an example consider the living room light. This appliance has an associated DIAC. This DIAC can have in its ACT list, a normal switch (by means of its ACT), a voice command device, a computer device, a remote control interface. Whenever the living room DIAC detects a message from any one of its associated ACTs it will react accordingly, e.g., switching on of off. An indication of status can also be obtained by issuing an adequate command message. This is useful, for example, to detect remotely if the lights are on or off. During the configuration procedure, the living room DIAC can be identified with a long name such as *living_room_light*, thus facilitating a lot the identification of the device.

Assessment of the B-Live System

A B-Live demonstrator was installed at the referred (CMRRC-RP) center in one of the houses for training patients (Fig. 4) before being discharged from the center. The demonstrator allows disabled users to operate appliances such as turn on/off the room, kitchen, WC, living room and corridor lights, open/close room blinds, front door and WC door, and turn on/off devices plugged in adapted mains power plugs.

Figure 4: A rehabilitation house at the CMRRC-RP

The B-LIVE system is almost a commercial product but it is still under development. As such, only informal evaluations have been carried out to assess the adequacy of the system to the requirements of its envisaged users. In this sense, CMRRC-RP patients evaluated the B-LIVE system in three occasions: August 2006, February 2007 and January 2008. In the first, three C5 quadriplegic users were able to operate all the B-LIVE functionalities installed in the house. In the second evaluation, a C6 paraplegic user lived in the house for a period of 48h. All users were able to successfully operate the B-LIVEπ system without having any earlier training on the user interfaces. The last trial was used to validate the current version of the system in order to start its offer as an assistive product.

Conclusions and Work in Progress

This paper addressed the use of CAN based systems to retrofit houses for quadriplegic people. A commercial system based on this fieldbus, named B-Live, is under final assessment. This system profits from the CAN characteristics to support soft real-time traffic used in commanding the house and hard real-time traffic transmitted by life-support systems. A B-Live demonstrator was installed at the rehabilitation center close to Aveiro.

Work in progress includes the full assessment of the proposed simplified FTT middleware used in the domotic nodes, and the integration of traffic from several life support systems. In the B-Live system some functionalities are still being developed, such as a food dispenser.

The B-Live system has been awarded with the Portuguese National Prize for Rehabilitation Engineering in 2007 (Called Jaime Filipe Prize).

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