Research Paper

First approach on the development of an agent designed for electric energy measurement in an Assistant Personal Robot

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ABSTRACT: *One of the most important challenges for mobile robots is the management of electric energy consumption in order to make decisions, reducing consumption or optimizing motion routes. The measure of the electric energy consumption can be used to estimate how much electric energy will be needed or used in the next planned task as a way to improve the effectiveness and autonomy of a mobile robot. This paper presents the development of an agent designed to obtain accurate electric energy measurement in an Assistant Personal Robot. The paper shows the implementation detail and firsts results obtained with this agent. Future work will be focused on modeling the energy consumption of the mobile robot.*
KEYWORDS: *Electric energy measurement, ARM microcontroller, Assistant Personal Robot*

I. INTRODUCTION

Mobile robots usually use batteries in order to provide electric energy to the on-board computer, sensors and actuators. The measurement of the electric energy consumption of these devices provides the information needed to estimate if the current or next task can accomplished, that is, the key aspect to determine autonomy. A low energy level in a battery powered mobile robot can causes a failure during the execution of a specific task, so taking the properly decision before the battery runs out can avoid compromising situations. There are several studies centered in different point of views to reduce, optimize, modeling or managing the energy consumption. For example, building power models from experimental data [1], using mathematical formulas [2] or finding optimal routes by minimizing the mechanical energy [3], among others. An example related on our purpose are described in [4], the paper focuses on study the energy consumption of a small lightweight two-wheel differential drive robot, building power models from real measurement from motion and sensing in order to reduce the motion energy consumption.

The Assistant Personal Robot (APR) was proposed as a remotely tele-controlled mobile robotic platform with telepresence services in order to provide assistance to elders and people with reduced mobility in indoor environments [5]. The mobile robot platform showed in this paper is the second version of the APR (Figure 1) which includes a more computational power and new sensors and peripherals. The availability of high computational resources has allowed the inclusion of additional features as SLAM, autonomous navigation and parallel processing data. This paper presents the first experience on developing a measurement agent specifically designed to obtain an accurate electric energy measurement in the mobile robot. The main idea is to use the capabilities of an ARM microcontroller in order to implement an autonomous measurement agent able to compute the instantaneous power and the total electric energy consumption in the mobile robot platform.

II. MOBILE ROBOT PLATFORM

The APR mobile robot provides interaction through a 12" touch screen interface and several Dynamixel MX-28T digital servomotors that have been used to develop assistive services for people with mobility problems [6]. The APR prototype used in this paper has an improved suspension system that reduces vibrations [7] during the displacements. The motion system is based on three omnidirectional wheels powered by three DC motors [8]. On the one hand, the mobile robot incorporates a LIDAR device Hokuyo UTM 30-LX, and a personal computer with an Intel Core i7-6700 3.40 GHz, 16 GB DDR4 RAM memory and 240 GB SSD hard disk (Figure 2). On the other hand, the mobile robot incorporates an electronic board based on ARM

microcontroller in order to control the omnidirectional wheels and the activation of all sensors and actuators. The electronic components are attached to the robot structure by using 3D printed pieces. The whole system is powered by three 12 V Lead-Acid batteries of 12 Ah. Recently, the APR mobile robot platform has been used in different applications such as a walk-helper tool [9], as early gas leak detector [10] and also proposed mobile robot self-localization and obstacle avoidance with a 2D tilted-down LIDAR [11].

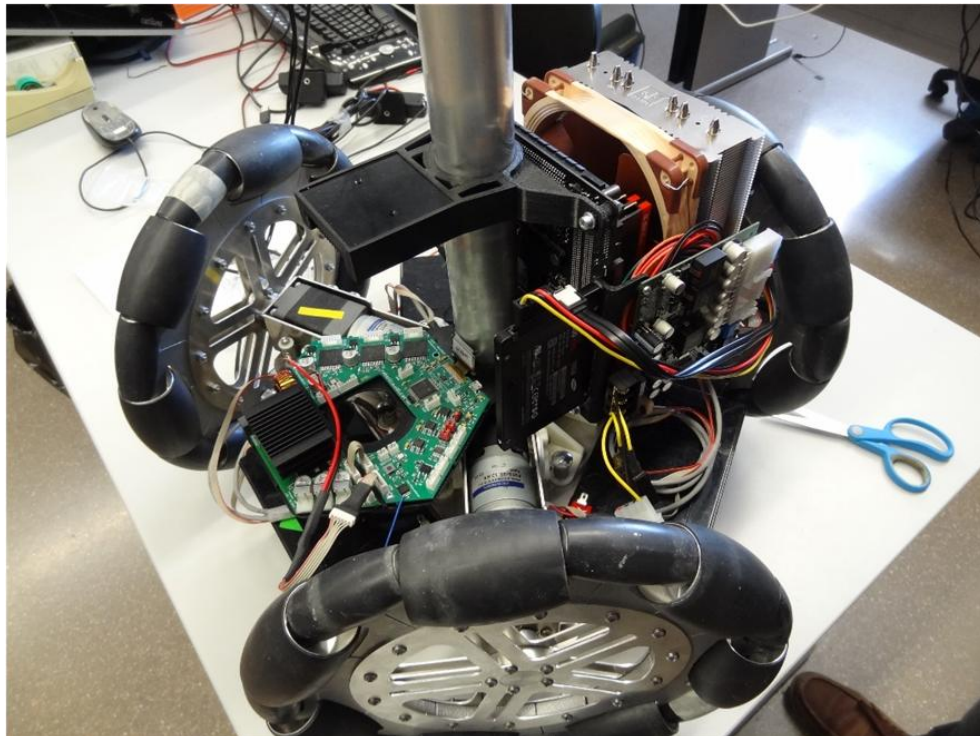**Figure 1:** Image of the APR prototype used in this paper.

Figure 2: Image of the omnidirectional wheels, DC motors, electronic boards, and main computer of the APR prototype.

*Corresponding Author: David Martínez   22 | Page
Department of Computer Science and Industrial Engineering, University of Lleida

The electronic control board of the APR performs the activation and supervision of all sensors, actuators, and peripherals of the mobile robot. The electronic control board has been designed to perform real-time measurement of the currents and voltages of the different batteries and devices of the mobile robot.

The electronic control board is built around an ARM microcontroller, STM32F407VGT6 from ST Microelectronics. The core is based on 32-bit Cortex-M4 operating at a frequency of up to 168 MHz, 1 Mbyte of Flash memory, 196 Kbytes of SRAM and working by 8 MHz external oscillator.

The electronic board includes several ZXCT1041, a bidirectional precision high side current sense monitor that provides an output voltage proportional to the differential input voltage based on a 3 W 50 mΩ shunt resistor, in order to sense the current spent by the different devices of the mobile robot. The output voltage of the current sense devices are connected to 12 bit ADC converters on the microcontroller.

The electronic board also includes an ACS712, a fully integrated hall effect-based linear current sensor that provides an output voltage proportional to AC or DC currents, in order to measure the instantaneous current spent by the personal computer that controls the mobile robot. This sensor allows measurements within a range from -20 A up to 20 A with a sensitivity of 100 mV/A which is slightly higher than the maximum current peak expected. The output voltage is connected to a 12 bit ADC converter on the microcontroller.

The voltage of the batteries are measured by a voltage divider in order to adapt the battery voltage levels to the microcontroller voltage range. The voltage divider is made up by two precise resistors: R1 = 150 kΩ and R2 = 30 kΩ. The output voltage is reduced within a range from 0V to 3V that represents the voltage from 0 V to 18 V, being 14.5 V the maximum voltage expected from the batteries.

The current and voltage sensors have been calibrated and modeled with a linear regression, establishing a relationship between the ADC values and the current or voltage data. Figure 3 shows the diagram connection of the sensors.
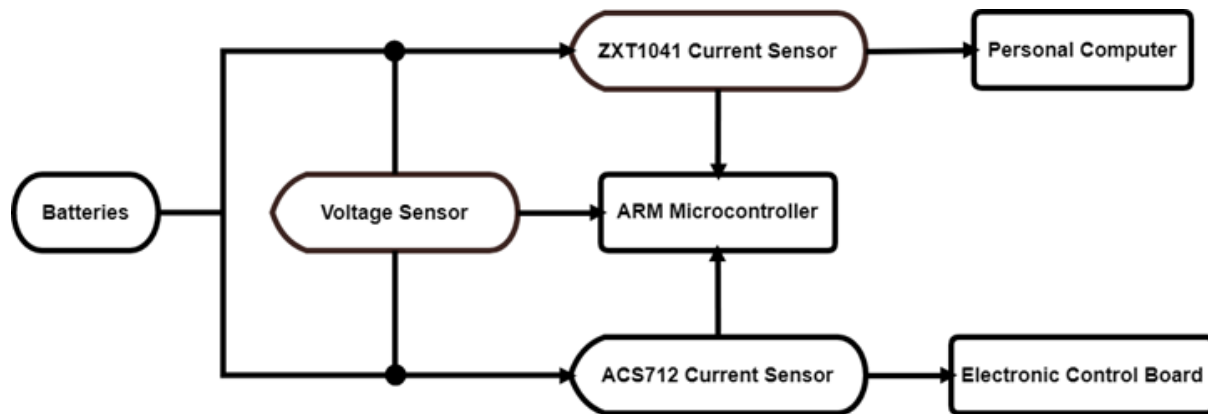

Figure 3: Block diagram of the sensors connection.

III.   ENERGY MEASUREMENT AGENT

The energy measurement agent has been implemented in the ARM microcontroller of the electronic control board. This microcontroller operates autonomously in the mobile robot and is able to provide real-time measurements. The estimation of the instantaneous energy spent is defined as the product between the current, voltage and the time lapse between consecutive measurements. The accumulated energy is obtained by integrating the instantaneous energy spent. The final objective of the energy measurement agent is to obtain an accurate evolution of the electric energy consumption on the mobile robot as a way to predict future evolutions.

The energy measurement agent is implemented as an automatic and periodic procedure using the following resources of the ARM microcontroller: a count up timer, an ADC converter and a DMA controller. Figure 4 shows the flowchart of all these resources.
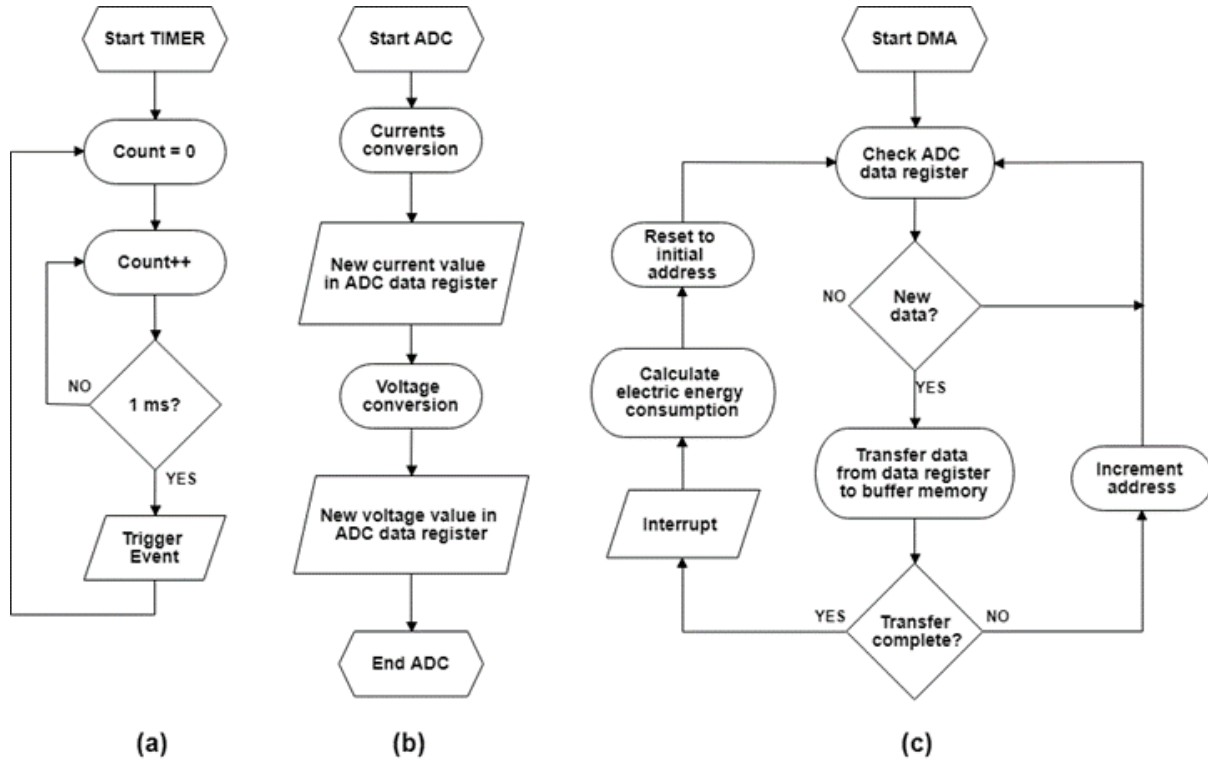
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Figure 4: Energy measurement agent: (a) Timer flowchart, (b) ADC flowchart, (c) DMA flowchart.

The measurement agent starts with the timer activation. The timer is programmed to generate a trigger event every 1 ms, this event triggers the ADC conversion. The ADC performs the currents and voltage conversions sequentially thought three independent channels. The converted data available into ADC data registers are transferred in a buffer memory by the DMA controller, which allows to save the data just when ADC conversion finished. All the conversions are carry out every 1 ms and it is saved 100 values of each conversion into a circular buffer. When the circular buffer is full it generates a Transfer Complete DMA Interruption and it calculates the electric energy consumption in the last 100 ms with the 100 current and voltage values. The timer continues generating the event that triggers the ADC, so the new current and voltage values overwrite the previous ones in the circular buffer. The electric energy consumption is stored periodically and can be consulted thought an ASCII command.

IV. RESULTS
This section presents the first results obtained with the energy measurement agent developed on the ARM microcontroller to obtain the electric energy spent by the APR robot. The mobile robot has been tested in two different scenarios. In the first experiment the mobile robot carries out several specific activities using the different actuators and sensors during approximately 6 minutes. Table 1 displays the different specific activities performed during the experiment.

Table 1: Activity identifier related with the activity performed.

Activity Identifier	Activity
A	Arms movement
B	Wheels forward movement
C	Wheels rotation movement
D	Arms movement and wheels forward movement
E	LIDAR enabled, arms movement and wheels forward movement

Figure 5 shows the general evolution of the current and electric energy data measured. The activity identifier indicates the related activity performed during the experiment. The current evolution shows that the

different activities require different current depending on the computational power required and the sensors and actuators used. The energy evolution shows changes in the slope caused by the different activities.

In the second experiment the mobile robot performs the exploration of a selected area during 5 minutes. The Figure 6 shows the evolution of the current and electric energy data measured. In this experiment the use of computational power, sensors and actuators changes during the displacement of the mobile robot although the overall slope of the energy is almost constant. In the future, the analysis of this slope will be applied to estimate the energy required for a planned mobile robot operation.
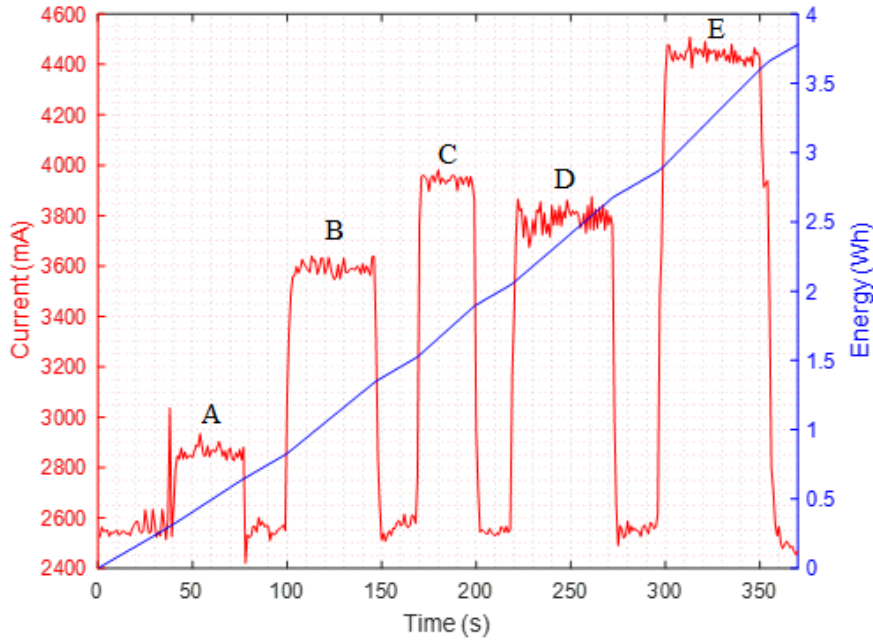

Figure 5: Evolution of the electric current (red lines) and electric energy (blue lines) during a sequence of short actions performed by the mobile robot.
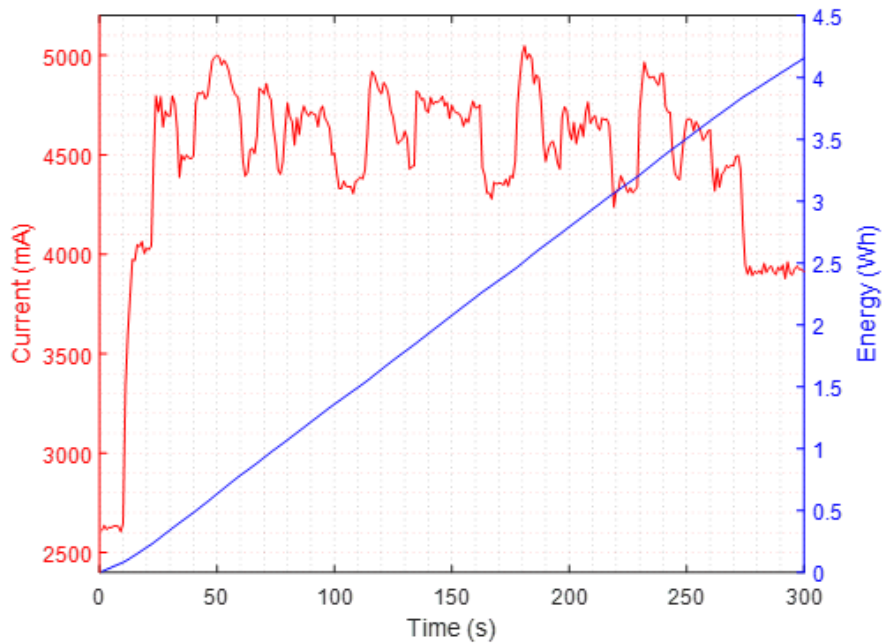

Figure 6: Evolution of the electric current (red lines) and electric energy (blue lines) during a complete exploration performed by the mobile robot.

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V.   CONCLUSION

This paper presents the first approach on the development of an agent designed for electric energy measurement in an Assistant Personal Robot. The evolution of the design of this mobile robot prototype includes more computational power and new sensors and peripherals and the energy management has become a crucial aspect in the autonomous operation. The measurement agent has been developed on an ARM microcontroller in order to provide real-time energy measurements by combining the use of a timer, an ADC and a DMA controller. The different currents and voltages of the different power sources of the mobile robot are sampled automatically every 1 ms and the overall electric energy consumption is updated every 100 ms. The results obtained in the first experiments performed have shown real-time measurement capabilities.

The final objective of this agent will be the estimation of the energy consumption in order to estimate the remaining running-time and the best moment to proceed to recharge the batteries. Future work will be focused on characterize the electric energy spent on different specific mobile robot actions in order to build an energy model useful to predict the energy consumption and autonomy of the mobile robot.

ACKNOWLEDGEMENT

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