Micro-sensor systems for central vacuum cleaners

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Abstract. *For an effective reduction of dust particles in the indoor air, central vacuum cleaners should be preferred over still popular hand-held vacuum devices since they are clean (dust and dirt are provided outside the room), anti-allergic (multi-filter techniques are applied), quiet (power unit is located in the basement) and lightweight (only the hose is held). In the paper, micro-sensor based improvements to central vacuum cleaners are presented, making the device adjustable to the actual carpet soiling, more efficient and more comfortable. This – among others – will strengthen the market position of such devices. The micro-controller based sensor devices were built using a combination of MCM (multi chip module) and SMD technology. To obtain a further size reduction, next generation 3D BGA-MCM packages could be applied.*

Keywords**:** home automation, indoor climate control, floor hygiene, smart sensors, multi-chip module

1. Introduction

In recent decades, new construction techniques and insulating materials have been developed which remarkably reduce the heat loss of buildings, enabling high energy savings at the cost of a diminished natural air exchange. For these highly-sealed rooms, sufficient indoor air quality and thermal comfort must be guaranteed by appropriate heating and ventilation along with a reduction of dirt and dust in rooms [1-3].

Vacuuming is a major source of indoor air pollution. Traditional upright vacuum cleaners force particles through a filtering medium (often nothing more than a porous paper bag) and back into the air of the same room. For an effective reduction of dust particles in the indoor air central vacuum cleaners should be preferred over still popular hand-held vacuum devices. There are strong motivations for central vacuum cleaners since they are:

- clean - dust and dirt can't re-enter the room, since it is whisked away to the central collector,
- anti-allergic – multi-filter techniques are applied,
- quiet - the power unit of the vacuum is far away, in the basement, garage, or even attic,
- lightweight - no heavy motor and dust bag to carry around, just plug in the hose into a special built-in duct in any room.

A commercial central vacuum cleaner have been installed in the SmartHOME test house [4] on the University Campus, Fig. 1. In the sequel, improvements achieved by added smart micro-sensors are described: A multi-sensor integrated in the handle of the cleaner measures the dust concentration, the air pressure and air velocity and the suction power. A second sensor module at the collector device measures air pressure and velocity and monitors the filter performance. With these data, the optimum turbine engine power can be adopted. This helps to improve the carpet-dependent cleaning process and reduces both power consumption and noise level. Failures during operations due to leaking, large dirt particles or dirty filters are immediately detected.

Fig. 1. *Demonstrator (front-side and back-side)*

2. Optimizing the cleaning process

In this section, measures are described to improve the performance of central vacuum cleaners and compare them to regular hand-held cleaners. A principle sketch of the sucking duct of vacuum cleaners is shown in Fig. 2.

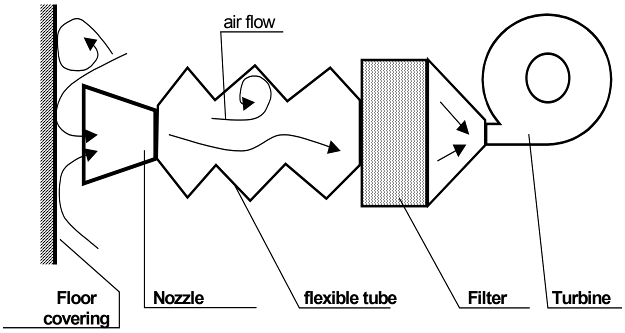


Fig. 2. Sucking duct of vacuum cleaners (principle)

Improvements aim primarily at three important features, which are closely interrelated: (1) improved particle sucking, (2) reduced electrical power, (3) reduced noise emission. In Table 1, for every of these goals, the responsible physical parameters and possible improvements measures are listed.

Table 1. Possible improvements of vacuum cleaners

goals	parameters	improvements
reduced electrical power	- el. turbine power - el. efficiency	- time control - adjustment of the sucking power level to th actual soiling - reduction of the air flow resistance
improved particle sucking	- volume flow - air flow shape - hose length, material - filter area, resistance	- higher pressure gradient - optimized nozzle design - adjusted hose length
reduced noise emission	- location of the host (collector) device - reduced turbine power - hose length, material - filter effectivity	- host (collector) device installed outside the living area - reduced, task-driven turbine power - highly efficient particle sucking - multi-filter technique

First, the turbine sucking power as well as the influence of the hose length on the cleaning process have been investigated. Tests have been carried out with two commercial vacuum cleaners: 1) Kärcher T201 vacuum cleaners [5]; 2) Allaway 1750 central vacuum cleaners [6]. A depression chamber box (50x50x50 cm) and a air mass-flow sensor Degussa VT Sensycon has been used. The energetically optimal mode of operation follows from the efficiency factor $\eta = P_{air}/P_{el}$, with P_{air}, P_{el} - air flow power and (turbine) electrical power, resp. The measurements showed, that the desired maximum sucking power as well as a high efficiency are dependent of the air flow velocity at the nozzle and on the hose length, Figs. 3,4.

For reasons of energy-saving and limited noise emission, it is highly desired to adjust the sucking power to the actual carpet's soiling. Hence, the dust concentration in the hose as a function of the sucking power (overall air resistance in the duct) and of the turbine electrical power has to be measured. Measurements with an infrared parcticle sensor (Sharp GP2U056) consisting of a light-emmission diode and a phototransistor showed that in order to avoid larger particles to cover or damage the optical sensor parts, it should be carefully sheltered or even placed in a small extra channel parallel to the hose.

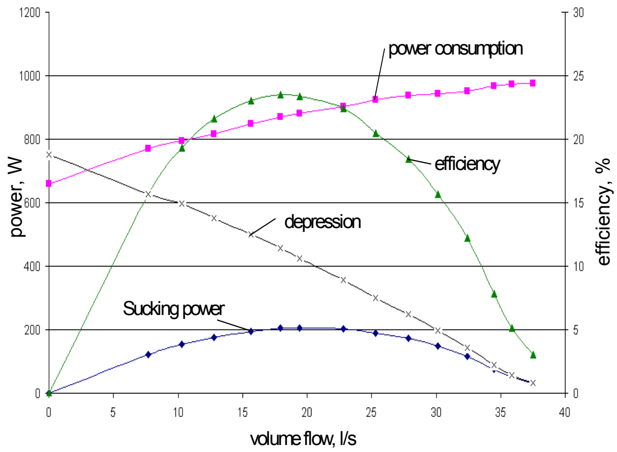


Fig. 3 *Measurements: Sucking power, power consumption and electrical efficiency as a function of pressure gradient at the nozzle.*

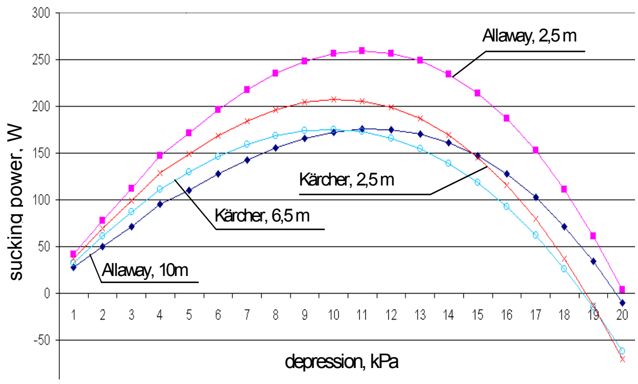
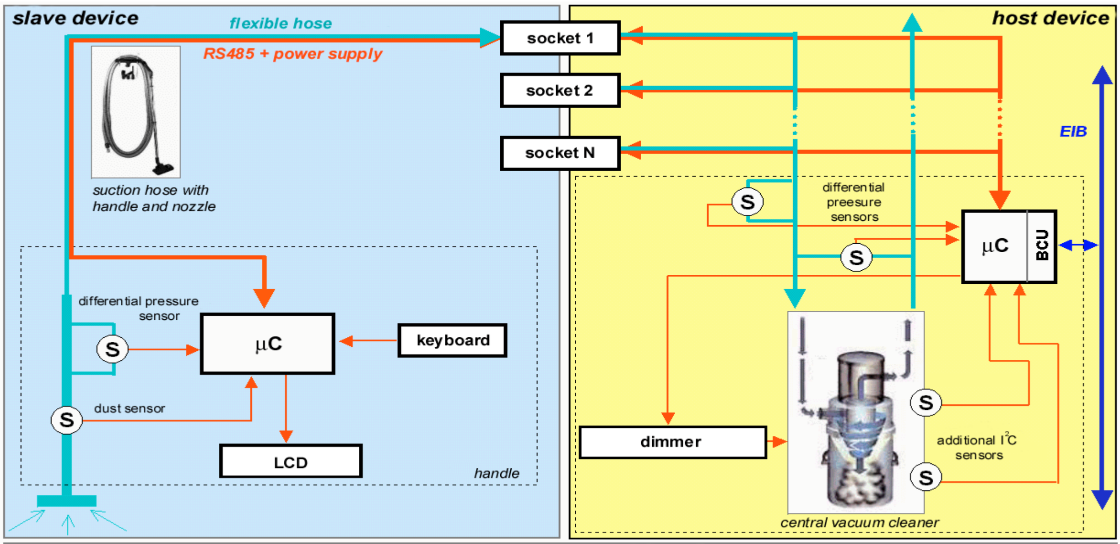


Fig. 4. *Measurements: Sucking power as a function of the pressure gradient and hose length*

3. Micro-sensor system design

The central vacuum cleaner consists of two main parts, the central collector device in the basement and the flexile tube (hose) with handle. The device should be controllable entirely from the mobile handle but offer some additional features for service and maintenance assistance at the central device.

The improvements enclose a micro-sensor system in the mobile handle and a second at the host device as well as a attachable diagnostic tool with a graphical user interface on a PC or laptop. On both the handle and the collector device displays inform about the device's performance data like cleaning progress, filter performance, dust level in the dust bin or failures. The device is connected with the smart home network structure via EIB couplers. In Fig. 5, the functional diagram of the overall system is shown.



3.1 Host device

In the host device (Fig. 6), a micro-sensor system has been implemented which measures

- the air velocity and air flow,
- the filling level of the dust bin,
- the device's temperature (for possible malfunction warnings).

A EIB home bus coupler is also included.

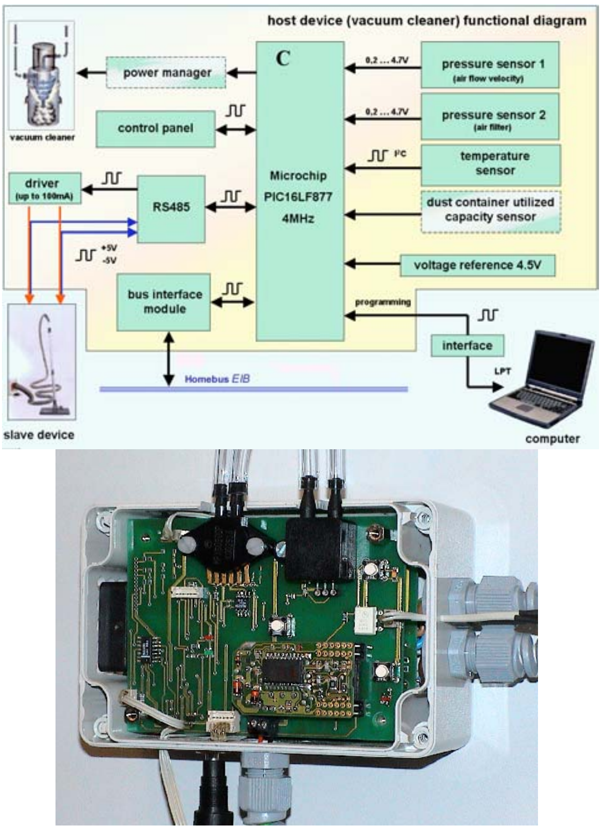


Fig. 6. Host device: functional diagram and view

3.2 Smart handle

In the handle, built-in sensors measure the air velocity and the air flow rate through the hose as well as the dust concentration in the sucked air. The smart micro-sensor system in the handle (Figs. 7,8) contains:

- a difference pressure sensor (Micromachines IMP-1040),
- an IR dust sensor (Sharp GP2U06),
- a Multi-Chip-Modul (MCM) incl. micro-controller (Microchip PIC16F877),
- a LC-Display (size 2x8),
- a keyboard with 7 keys.

The unit is supplied either by a Lithium battery cell or from the host device.

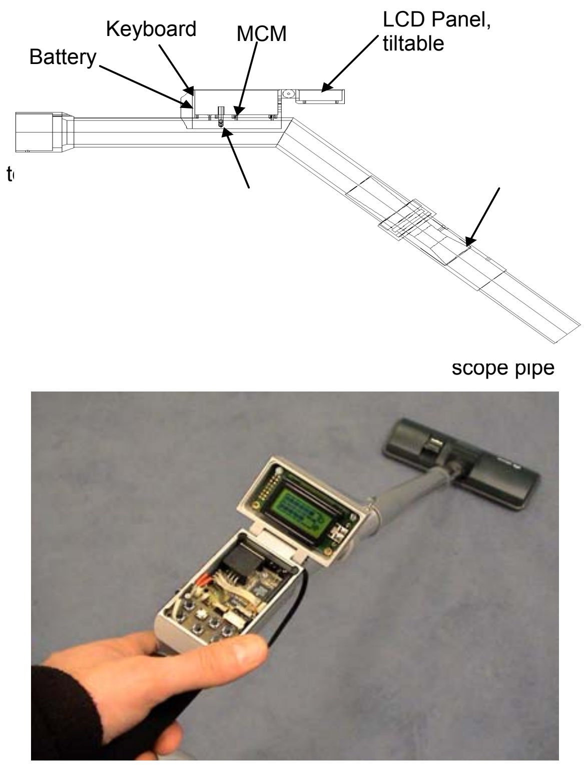


Fig. 7. Smart handle: Schematic and view

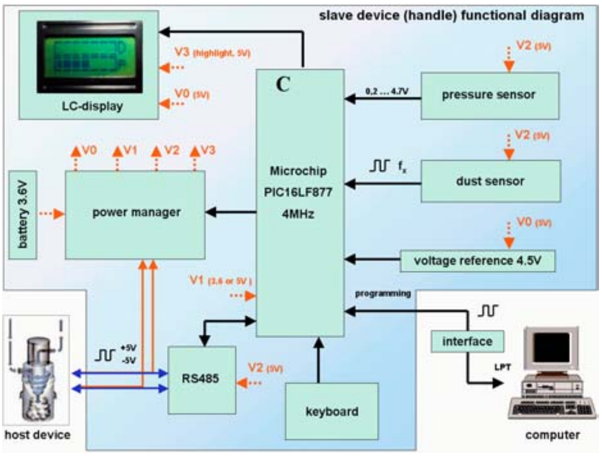


Fig. 8. Smart handle: functional diagram

4. User interface

The system offers three "information windows":

- LCD of the handle (see Fig 7),
- LCD at the host device,
- monitor program at a plugged-in, EIB connected diagnostic tool (PC, laptop etc.).

The LC display in the handle informs about the dust particle concentration in the hose (and hence the carpet cleaning progress) and indicates failures during operation. The display at the host device shows the actual measurements at that device (air flow, particle concentration etc.) and informs about failures and filter performance degradation etc.

The monitor program „Central vacuum cleaner" (Fig. 9) serves for control of the overall device. The following parameters are monitored:

- air flow rate through the hose,
- air flow rate through the handle,
- turbine sucking power,
- leakages (air flow losses),
- increasing pollution of the air filters,
- expected battery lifetime,
- status reports, failure messages.

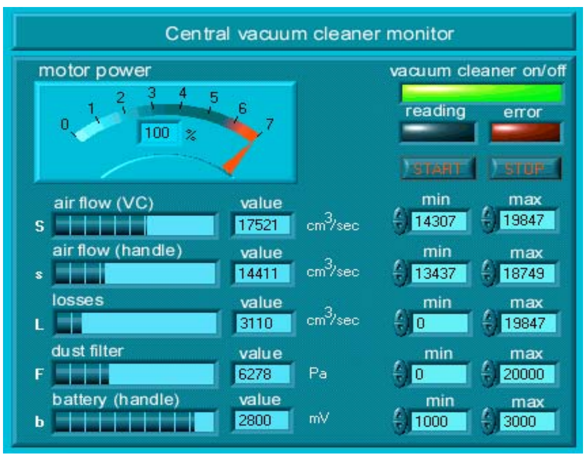


Fig. 9. Monitor program

5. Outlook

The described application shows in general, how due to smart micro-sensor design, established devices and technologies can be further improved and the user comfort can be greatly enlarged at low cost.

The presented solutions were designed in combined SMD-MCM technique. For further size reduction, a flexible 3-layer BGA-MCM technology [7] could be applied. The complete networked smart sensor is essentially a 25x25mm^2 3-layer stack consisting of (from top to bottom) (1) the sensor layer, (2) the processing layer, (3) the data communication (bus coupling) layer. An example for such 3-layer stacks built in the cleaners handle is shown in Fig. 10.

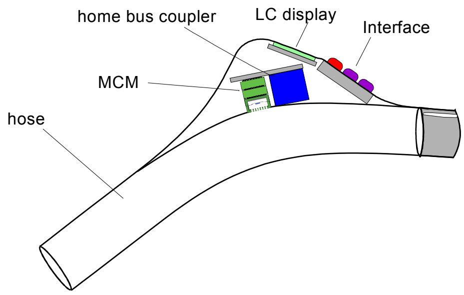


Fig. 10. 3-layered BGA-MCM chip in the handle (design study)

The widespread use of central vacuum cleaners in Scandinavia and North America proof the benefits of such devices for private homes. It is highly desired to look for broad support and further technical improvements, so that often-mentioned disadvantages like high purchase and installation costs, difficult retrofitting and complicated conservation could be eased. This way, these modern and comfortable household devices could gain more acceptance worldwide, opening new market prospects.

Acknowledgements

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