Development of a Range of Robot and Automation Prototypes for Service Applications

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1. Introduction

It has been suggested that the robotics and automation research will move more and more towards the service sector, rather than the more structured factory jobs as in the past (Engelberger 1989), (Schraft 1994). A number of service robots have been developed worldwide in recent years, including an increasing number for the healthcare sector. Examples include the HANDY-1 robotic arm for feeding the severely disabled (Whittaker 1992), (Jackson 1993), Meal Assistance Robot System (Ishii *et al.* 1991), MANUS wheelchair mounted robotic arm (Kwee 1998), KARES rehabilitation robotic system (Song *et al.* 1998), Care-O-bot mobile home care system (Schraft *et al.* 1998), THR hip replacement surgical robotic system (Paul *et al.* 1992), CERO robot for assisting partly motion-impaired people to transport light objects in an office environment (Huttenrauch *et al.* 2002), and WorkPartner for interactive work with humans outdoors (Ylonen *et al.* 2002).

While the above examples provide direct services to the end users, the authors in City University of Hong Kong (CityU) have focused their attention on developing facilities to support maintenance or auxiliary-aid services such as cleaning, delivery, and inspection in vast but difficult to reach/manage places. Although these are less glamorous or prominent chores, they are nevertheless essential routine services often associated with a substantial tedium and lack of stimulating challenges. Additionally, these services may also include safety risks, as in the case of washing windows on high-rise buildings, moving through a maze of dilapidated ventilation ducts, or delivering to, or cleaning, a hospital ward accommodating infectious or infection-sensitive patients.

Such safety risks or convenience of service provided further emphasise the benefits of automating these monotonous tasks. CityU robotic systems reviewed in this text have been arranged approximately in the order of diminishing risk to operators from the targeted activities. Some originally developed supporting technology has also been included.

2. “Cleanbot” Climbing Robots for Remote Maintenance and Cleaning

Traditional manual methods of inspection and maintenance of tall buildings normally require the construction of temporary scaffoldings or permanent gondola systems for workers to stand on in mid-air or at high altitude. Inevitably, this increases the cost and slows down the operations. Additionally, the workers are at risk of falling from life-

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threatening heights. In order to automate these operations and reduce the overall hazards involved, climbing service robots are needed. Because it is unlikely that any single robot configuration could suit all different types of modern high-rise buildings that tend to be uniquely shaped one-off designs, three types of climbing service robots have been developed at CityU, "Cleanbot I", II and III (Tso *et al.*, 2000). While all three rely on vacuum grippers for climbing, they belong to quite different mechanical designs.

The largest and heaviest of the three robots is Cleanbot I shown in Figure 2.1. It is designed mainly for cleaning large glass-wall surfaces with window frames protruding up to 40 mm. It is pneumatically actuated and has four DOFs: three linear and one rotational about the axis perpendicular to the wall. Weighing about 30kg and measuring 1.3×1.2×0.4-deep m, it can move on glass-walls through a sequence of steps (up to 0.4 m long) by swapping its vertical and horizontal frames (Tso *et al.* 2000). The glass-cleaning unit consists of two special cleaning squeegees attached at both ends of the horizontal cylinder. Cleaning liquid is supplied to the squeegees to clean the glass. A sucking system is attached to the squeegees to collect a high proportion of the sewage.

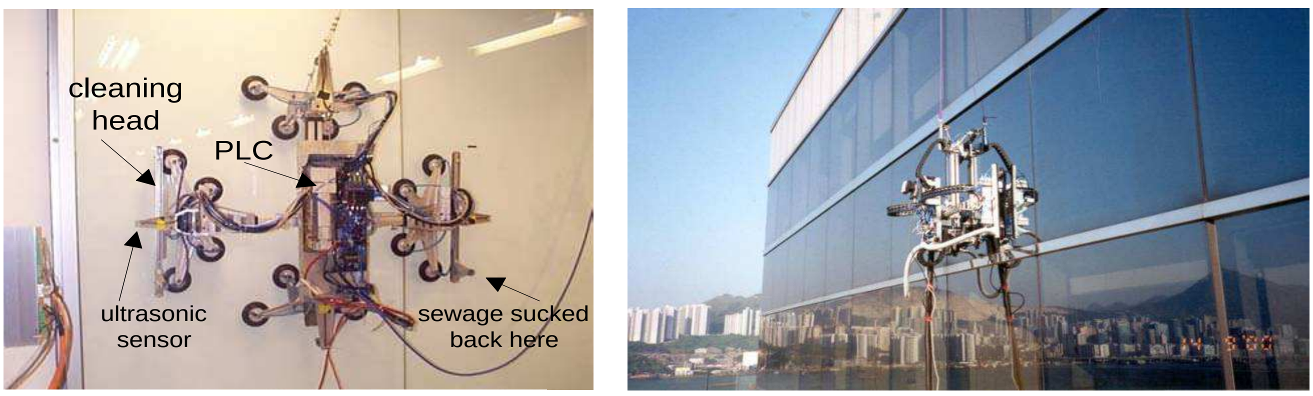

Figure 2.1 "Cleanbot I" Climbing Robot

Two main rodless cylinders are controlled by two sets of solenoid valves in parallel, one of type noted for large air-flow capacity and the other for high-speed response. The motion speed is thus not compromised for precision. The main cylinders are also equipped with pneumatic locking units for more agile and precise stopping. Two additional short cylinders are used for the robot rotation (in 1.6 ° increments) to align it with the window frame. The position sensors on the main cylinders are rotary encoders with rack and pinion mounting. One ultrasonic sensor is located at each end of both main cylinders. Their feedback is used to devise the window-pane cleaning path and cross to the following pane when appropriate.

Cleanbot II shown in Figure 2.2 uses one large vacuum gripper and electrically actuated wheels. It moves on large flat surfaces including tile walls with small air-gaps or unevenness, and can cross 10mm high obstacles. It is

Figure 2.2 Climbing robot "Cleanbot II"

Figure 2.3 Climbing robot Cleanbot III

relatively fast, low cost, and easy to manoeuvre. Cleanbot II provides smooth motion. It is shown in Figure 2.2 with a wet scrubbing cleaning attachment.
Cleanbot III (Figure 2.3) uses a chain-track to move its 52 legs, each with a suction cup and passive compliance (CIDAM 2004). The robot provides smooth continuous motion and can step over window frames and obstacles 35mm high.

3. Wall-tile Debonding Inspection Robot and its Variants for High-rise Buildings

Facades of many concrete high-rise buildings are tiled or similarly clad for decoration and weather protection. Due to factors such as uneven temperature distribution, acid rain, and poor initial workmanship, these elements tend to debond before the end of the expected building life. In order to prevent loose tiles from falling and causing injuries, tile debonding inspection is frequently required. The manual method commonly used involves impacting every tile or wall region with a standardized hammer and listening to the tone-feedback. The sheer size of the building facades (there are approximately 50,000 high-rise buildings in Hong Kong alone, many rising well over 100 m) and the necessity of impacting every part at multiple characteristic locations make this task fatigue- and error-prone. It is also hazardous, requiring work in mid-air at high altitudes. The quality of the outcome is questionable in terms of the consistency of the inspection coverage and the workers' subjectivity in distinguishing the difference in the tone-feedback of impact sounds from the solidly bonded and debonded tile segments during countless hammer-strikes. Yet, bonding failure is a cause of serious concern, as even a single 250 g tile falling from the 10^{th} floor height can gain a deadly momentum of 60 Ns at the ground level.
In order to improve the efficiency, accuracy and safety of this hazardous and markedly fatigue-prone manual inspection work, a robotic-NDT (non-destructive testing) system has been designed and constructed. It mimics the standardized manual inspection method. It is carried by a gondola-like structure which is driven by cable. Its key hardware components, an early hammering module and an impact-echo (feedback) acquisition module, are illustrated in Figure 3.1 together with a representation of an incompletely bonded horizontal tile. Estimating the extent of the void enclosed underneath the tile is the objective of the signal analysis module.

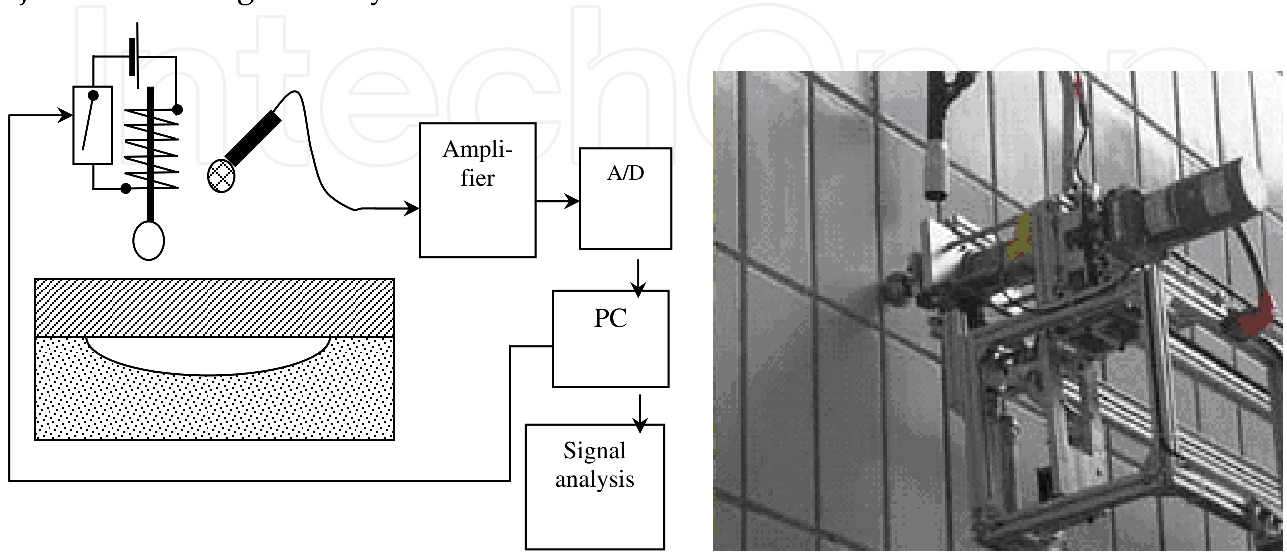

Figure 3.1 Major hardware modules and the system in operation

3.1 Theoretical Background

It can be readily shown that the fundamental frequency of flexural resonance of the tile increases with diminishing size of the void underneath it − for the same tile thickness (Tso *et al.*, 2000). The impact-generating side of the problem is modeled here by a two-degree-of-freedom spring-mass system, Figure 3.2. One spring with stiffness K_f represents the tile deflection, and the other spring with stiffness K_c represents the nonlinear contact stiffness. The two masses, M_2 and M_1, represent the tile and the impacting sphere, respectively.

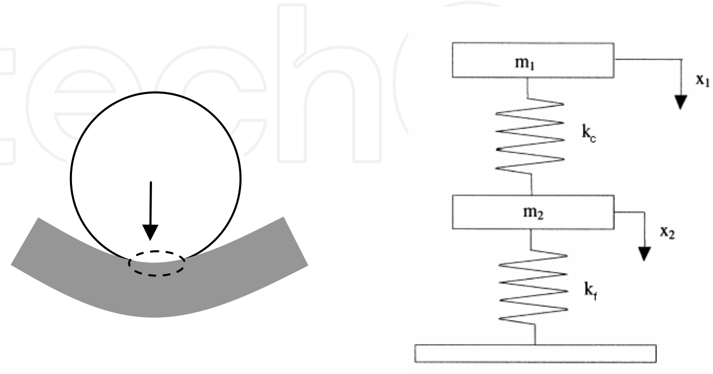

Figure 3.2 The spring-mass model of impact

Considering the energy distribution in the system, the original kinetic energy of the sphere deforms the structure during the impact. Assuming that the structure is elastic, as it reaches its maximum deformation the velocity of the sphere is zero and all of the initial kinetic energy has been converted to the energy stored by the deformation of the structure. Therefore, ignoring the shear and membrane components of structure deformation, the energy balance equation can be given as:

$$E_{sum} = \frac{1}{2} M_1 v_0^{\ 2} \approx E_f + E_c = E_f + E_{c1} + E_{c2}$$

where v_0 is the initial sphere speed, the subscripts *f*, *c* refer to the energy stored in the elastic deformation of the structure and sphere indentation in the contact region (c_1 pertains to the sphere and c_2 to plate).

It can be shown that the ratio of energy converted into flexural vibration depends on the thickness and radius of the plate. In the tile-wall structure, the thin tile layer caused by serious bonding degradation has small thickness and effective stiffness, leading to much stronger flexural vibration under impact compared to a solid tile-wall. Based on acoustics theory, the intensity of sound radiation is proportional to the vibration energy. Thus, the intensity of sound excited by flexural vibration after the impact can be used as an indicator for the structure-integrity identification for the tile-wall.

According to theoretical analysis for a degraded tile-wall, the thin tile layer formed by a void separation underneath will lead to the absorption of most of the kinetic energy of the impacting sphere through the flexural vibration mode of the tile. For a solid tile-wall, however, the loss of kinetic energy of the sphere is very small.

The strength of free vibrations of the sphere caused by impact indentation is also affected by the *vibration energy factor* $\lambda = E_f/E_{sum}$. As a result, the relative intensity of sound radiated from the vibrating sphere and plate can indicate the integrity status of the tiled structure.

Define R_{ps} as the ratio of sound intensities from the sphere and plate. Because the solid tile wall is generally over 20 times thicker than the thin layer of debonded tiles, the ratio of the sound intensities from the sphere and plate after impact R_{ps} will appear significantly different in the presence of debonding. Using this impact sound method, the need to use earlier reported coupling agents or to apply high pressure on tile-walls, can be avoided.

3.2 Void Size Versus Fundamental Frequency

By representing a tile with the void underneath as a thin rectangular plate of thickness *h* with simply supported edges, it has been shown analytically that the fundamental frequency of flexural resonance increases with diminishing size of the void (Rossing *et al.* 1994). Moreover, the shape of the void also has a significant influence on the fundamental frequency.

This finding forms the theoretical basis for operation of the robotic-NDT system shown in Figure 3.1. The system performance has been tested in practice on solid and degraded (with various debond size) tile-wall surfaces. In Figure 3.3, a stable spectrum peak at about 6.7 kHz is attributed to the free vibration of the steel ball. Other resonance frequency components are caused by flexural vibrations of the void-including tile structure. It is evident that with the decreasing void dimension the measured fundamental frequency increases from about 300Hz to 2.3 kHz, 2.9 kHz and 4.0 kHz. The measured and theoretical (with assumed parameters) fundamental frequencies for 7 cases with different void sizes in the specimens and site tests are given in Figure 3.4.

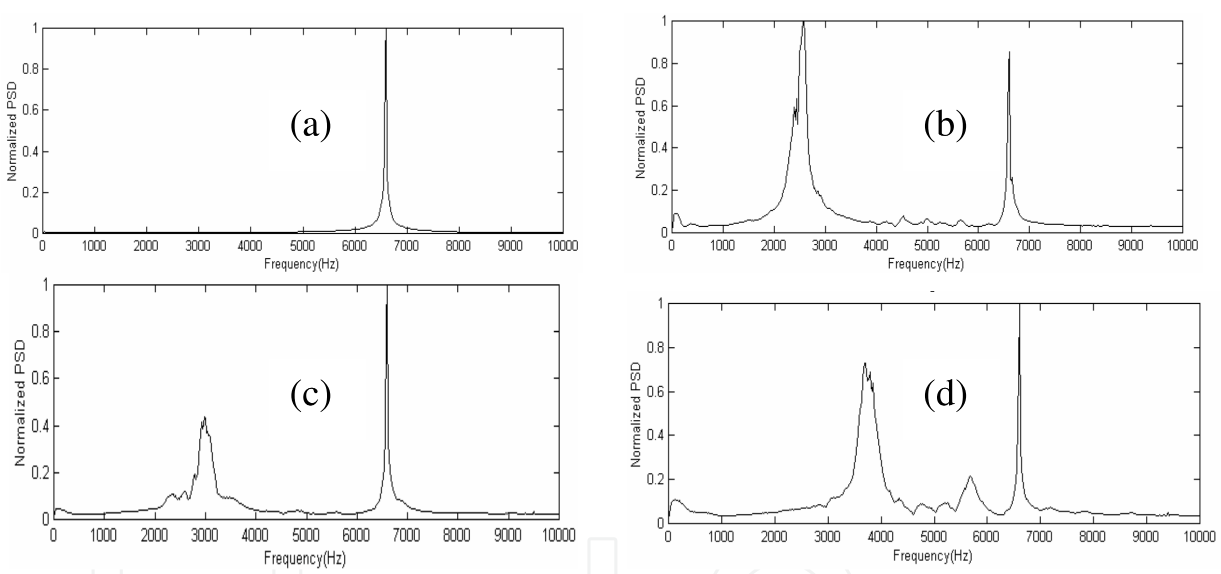

Figure 3.3 Impact sound feedback spectrum from a solid tile wall (a),
from a tile wall with the debond size 160mm×114mm (b),
with a debond 120mm×114mm (c), and with a debond 80mm×114mm (d)

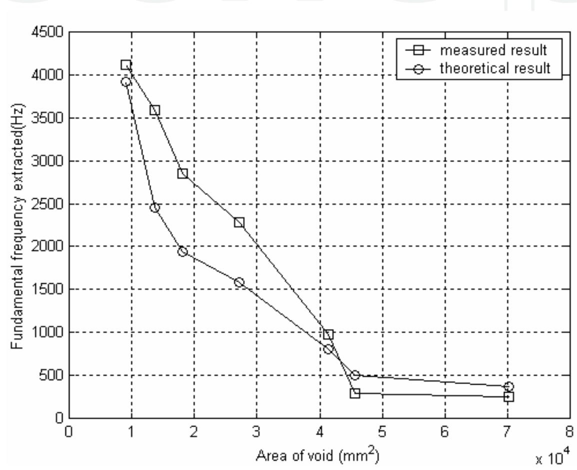

Figure 3.4 Theoretical and measured fundamental frequency versus debond size

The deviations between the theoretical (based on assumed geometry) and measured values are caused by many factors. Background noise and microphone distortions are just some of the disturbance effects. While the system therefore can provide only a rough estimation of the void size under individual tiles, there is little difficulty in identifying whether there is a void or a solid bond underneath.

3.3 Auxiliary Equipment

Typically, one or more camera may be mounted on the robotic-NDT system to enhance its functionality on a high-rise building. In CityU, an automated spray gun shown in Figure 3.5 has been programmed to automatically mark debonded areas of the tiled wall for subsequent repairs, a function often allied to the inspection itself for many end-users. The device combines an airbrush and a solenoid. When energised, the compressed air-flow causes the paint to be sprayed on the wall (Figure 3.5). This auxiliary equipment, just as the robotic-NDT module, is supported on the same gondola-like structure using a cable drive (partially visible in Figure 3.1). As there is no need to support workers, the entire mechanism is much lighter and structurally simpler than would be needed for conventional gondolas with workers.

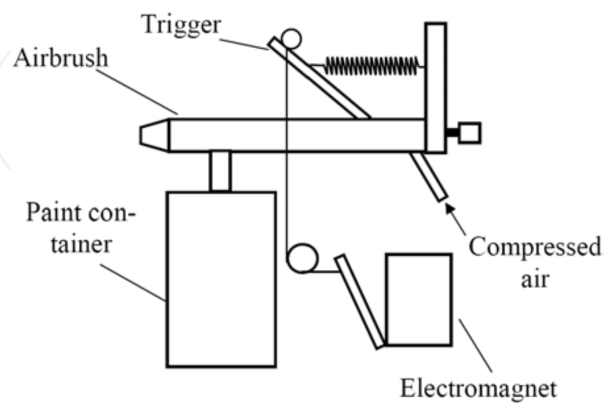

Figure 3.5 Automatic spray gun marks debonded tiles

The full robot system has been designed for semi-autonomous operation. It can be telecontrolled from a base station to perform a raster scan on the wall surface, or the operator can guide it manually in a master-slave control configuration mode. The measurement obtained from the NDT tool is transmitted to the base station via RS422 and displayed graphically for decision making. The master controller is a PC which collects and displays all data in terms of positions, NDT signal and motion control. The on-board computer system is used to monitor the data flow and carry out data conversion. Only processed data are transmitted from the slave controller to the master.

Other fixtures may be developed and incorporated into the basic structure, to perform specific service tasks as assigned according to the application. In particular, a CityU custom-built cleaning mechanism has been used with this basic robotic system with a high degree of containment of undesirable water splash during liquid wash for a high-rise building.

4. Two Service Robots for Hospital Applications

Two service robots for hospitals are described in this section: one for automatic floor cleaning and the other for general-purpose courier services, including the logistical support of telemedicine. These robots can navigate on their own in their application environments. By automating the respective routine but essential services, the aim is to reduce close contacts between non-medical staff and patients, thereby lessening the risk of spreading diseases. The sheer number of casualties and infected among the hospital employees during the recent SARS outbreak, and their suffering, attest to the significance of this aim.

4.1 Automatic Floor Cleaning (AFC) Robot

Adapted to public hospitals in Hong Kong where wet mopping and dry dusting are carried out daily, the cleaning staff must bend to access the areas under the beds (Figure 4.1). Not only does this slow down the cleaning process and is the work physically more demanding, but it also inconveniences the patients and puts the staff at risk of contracting diseases during their unavoidably close proximity to the patients.

Shown in Figure 4.2, the developed AFC robot can navigate autonomously, move under beds, avoid obstacles, vacuum dust, and spray disinfectant. Since it is battery powered, its path planning had to be carefully designed to avoid cleaning the same area repeatedly. This task has therefore been partitioned into the "Strategic" and "Reflex" layers shown in Figure 4.3.

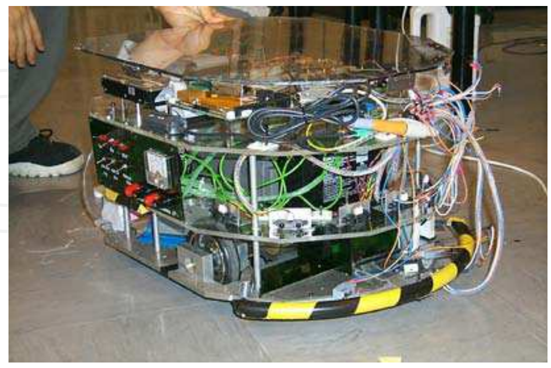

Figure 4.2 Automatic Floor Cleaning Robot Prototype

Implemented on an embedded PC, the Strategic layer is responsible for the path-planning, position estimation, and all strategic decision-making such as path correction. Implemented on a 68HC11-based "Handy board", the Reflex layer is responsible for all the low-level control and data acquisition of the robot, including the quick actions to deal with dynamic obstacles and unexpected events. Such actions are triggered by the sensor feedback.

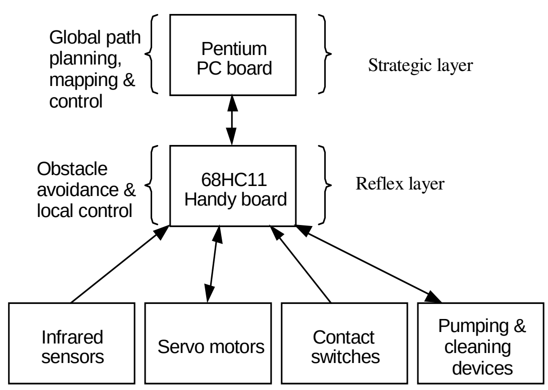

Figure 4.3 Control System

For obstacle detection, the robot is equipped with six IR-based distance-measurement sensors (Sharp-GP2D12) on the sides of the robot. Two additional sensors on top of the robot are for aligning the robot with the bed-edge when entering under beds using a dedicated algorithm. A light bumper, Figure 4.4, is also included. It operates two contact switches that can detect any side of the vehicle subject to impact to avoid conceivable obstacles.

Figure 4.4 Bumper

For the path planning, the cleaning area is divided into 24 squares illustrated in Figure 4.5. This simplifies the mapping process and data communication between the Strategic and Reflex layers. The robot starts at the square 1 and stops at square 24. Should there be no obstacles, the robot would follow the path shown in Figure 4.5 to finish the cleaning task. However, should it encounter obstacles, the robot takes an "obstacle avoidance" path to prevent a potential collision. If an obstacle is suddenly placed in front of the robot, the mechanical switch or the sensory system stops the robot immediately.

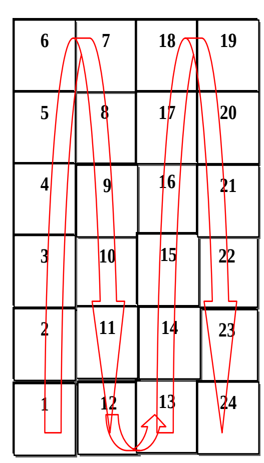

Figure 4.5 Path Planning

Four elementary strategies for avoiding obstacles are shown in Figure 4.6, labelled as "A", "B", "C", and "D". Strategy "A" is used when advancing forward; "B" when the obstacle is where the robot is about to turn to. Strategy "C" is used when the robot's turning path is blocked, and "D" when the obstacle is before a corner. In the first instance at this elementary level, obstacles are assumed to be smaller than the squares in Figure 4.6. Otherwise, they are treated as multiple obstacles, each one smaller than the square.

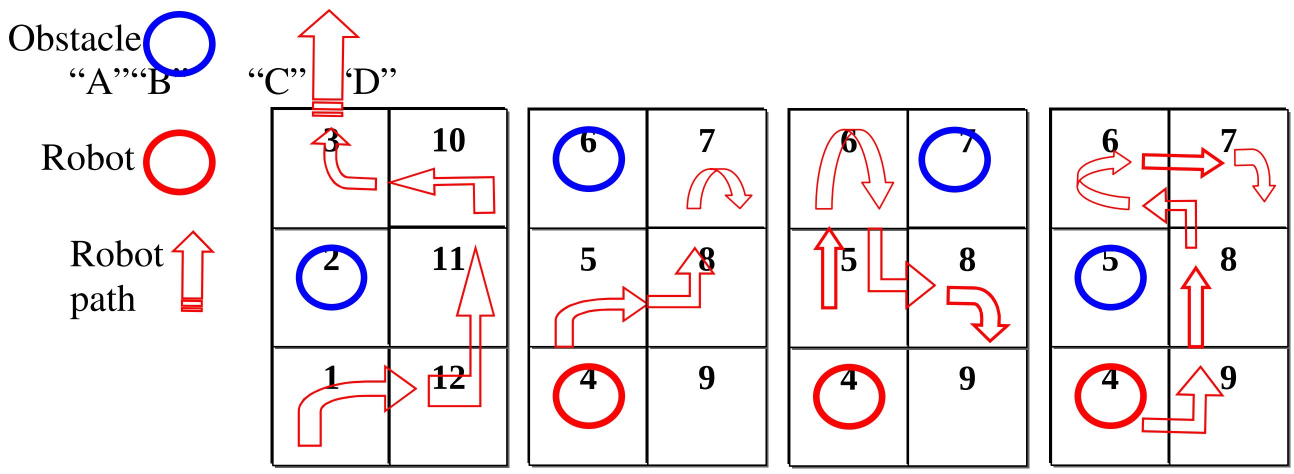

Figure 4.6 Four elementary Strategies

4.2 Multi-Purpose Autonomous Robust Carrier for Hospitals (MARCH)

MARCH is an autonomous transport system designed for door-to-door and floor-to-floor delivery using corridors and elevators. It accepts and carries a trolley with up to 300 kg of load such as meal trays, rubbish, linen, drugs, or other supplies including remotely controlled health-monitoring devices in logistical support of telemedicine.
Shown in Figure 4.9, MARCH robot uses short- and long-range infrared sensors for navigation and obstacle avoidance. The former are installed along the perimeter of the vehicle for avoiding obstacles and for wall following. The long-range sensors are used for detecting obstacles in front of the vehicle to facilitate local path planning.
To cope with the floor-to-floor mission, a specially designed robot arm is mounted on the vehicle to operate the elevator buttons. Since multiple robots could be used in the hospital, a central monitoring system based on 2.4 GHz wireless LAN technology has been installed to facilitate information exchange between the mobile vehicle and the control centre.

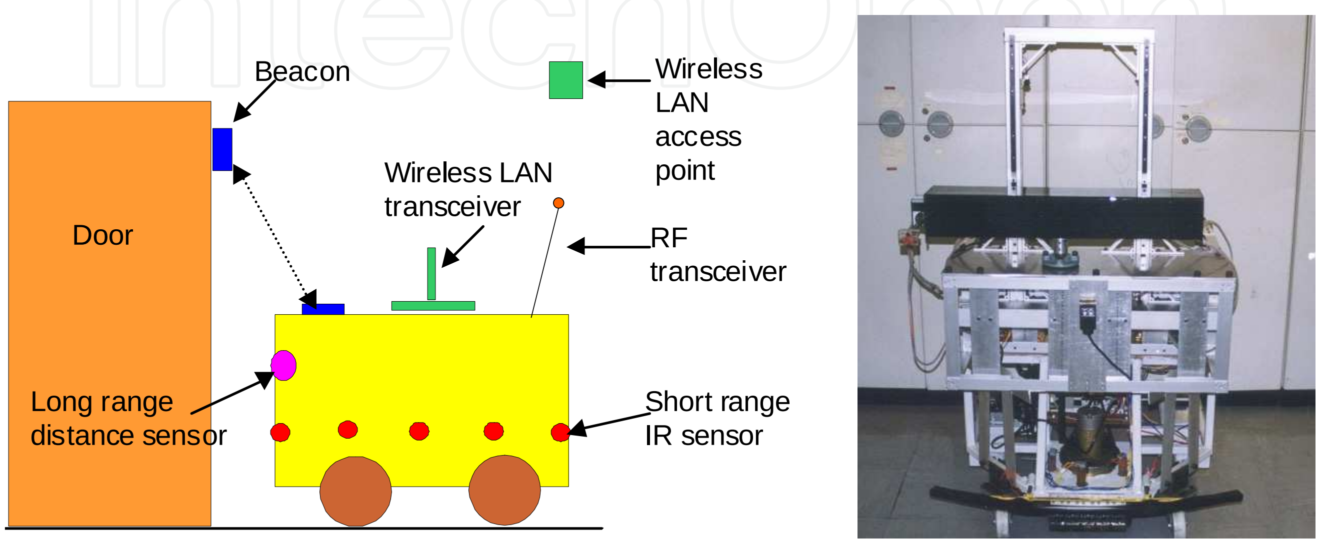

Figure 4.9 Navigation Support Schematics and Photograph of MARCH

The MARCH robot navigation combines the wall-following strategy, local path planning, IR beacon-based landmarks, and central monitoring. The destination and the preferred route are issued from central control room via the wireless LAN. To locate the position of the robot, beacon-based landmarks are adopted and are normally fixed at corners, doorways or places where beacon information is needed. Each beacon contains a unique ID code transmittable to the vehicle through a short-range IR communication device. The vehicle would be able to identify its position in the hospital map based on these ID codes and send it back to the centre via the wireless LAN for monitoring purposes.
A three-input (front/left/right proximity sensor) and two-output (speed, direction) fuzzy logic controller has been designed for collision avoidance. Two schemes of operating lifts are being investigated. One is based on a Cartesian robot manipulator for operating lift buttons and requires a simple vision system for the recognition of lift buttons, which slows its operation but requires no modifications to the lifts. The other scheme relies on the RF interface with the lift control system, which operates faster but requires prior installation work on lifts.

4.3 MARCH Robot and Telemedicine

Telemedicine for the remote delivery of home healthcare is in an advanced stage of development with multifunction devices, some wearable, included for the purpose of pre-diagnosis, patient-monitoring, and tele-consultation. With the MARCH delivery vehicle, this concept can include infections departments of hospitals for the delivery to patients of Bluetooth-enabled medical devices. As part of a larger telemedicine project, CityU team has contributed to the development of a “Medical Plug And Play” communications protocol and a multifunction stethoscope with simultaneous acquisition of ECG and heart and lung sounds. MARCH would be a delivery vehicle for this and videoconferencing equipment, and would host the required portable module for data compression and encryption, and for Bluetooth and Internet communication. With further development, it could also carry a longer teleoperated arm for the remote stethoscope manipulation.

5. Baggage-Carrying AGV

The intended purpose of the service AGV (automated guided vehicle) is to carry passenger luggage at airports, shopping malls, museums or theme parks for people with special needs. As the host passenger moves along corridors (structured or otherwise) on foot or in a wheelchair, the AGV loaded with baggage will follow him/her a small distance behind. Since the human user is within the operation loop, the AGV is not required to perform highly complex tasks such as comprehensive understanding of the environment or precise path planning. A low-cost, simple sensor and control system would suffice for this type of application. Important functions for the AGV are to identify the direction where the host passenger is, and avoid hard collisions. Within reason, accurate maintaining of the distance between the host and the AGV is not fundamental. Hence, the AGV is mainly concerned with two distinct task-achieving behaviours: (i) passenger following and (ii) collision avoidance.

5.1 Passenger Following

For the passenger following task, the passenger must wear a sonar emitter. There is a rotating sonar receiver on the AGV, Figure 5.1. For every full revolution, this receiver memorizes its principal angular orientation, θ, that provided the best alignment with the sonar emitter on the passenger. This reference is then used to generate steering commands for the vehicle motion direction.

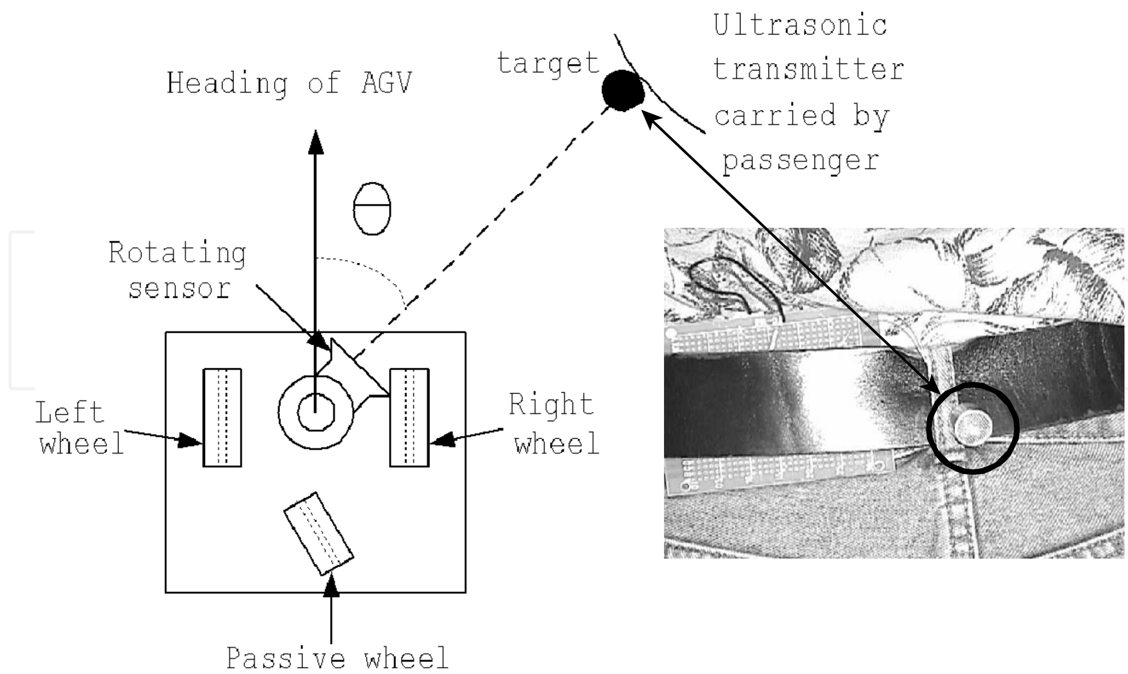

Figure 5.1 The Concept of the Passenger Following Task

The maximum signal intensity received during the sensor revolution, A_{max}, is checked. If it is greater than a preset threshold, the AGV is then deemed to be too close to the passenger and is stopped to wait for the passenger to move further.

5.2 Collision Avoidance

Many types of bumpers, levers and similar mechanical structures rely on the stiffness of the structural elements to transmit the contact forces onto sensing or switching elements. They may perform satisfactorily at very low AGV speeds when instantaneous stopping of the vehicle is possible. However, the short range of contact/tactile sensing is the constraint that limits AGV speed so that the vehicle stopping distance would not exceed this range. In order to increase the tactile sensing range and allow larger AGV speeds that result in larger vehicle stopping distances, fibre optic 'curvature gauges' (Djordjevich and Boskovic 1996) sensitized to their geometric curvature are arranged in loops around the AGV. One configuration of such loops is shown in Figure 5.2. When the AGV is driven into other objects (obstacles), these loops deform, resulting in the change of their curvature – which the specially sensitized optical fibres detect. Compared to the traditional bumpers and whiskers used in the past for a similar purpose, the difference here is that no intermediate mechanical elements are employed to either transfer the impact loads onto the sensitive element or provide mechanical compliance during the impact. Optical fibres themselves

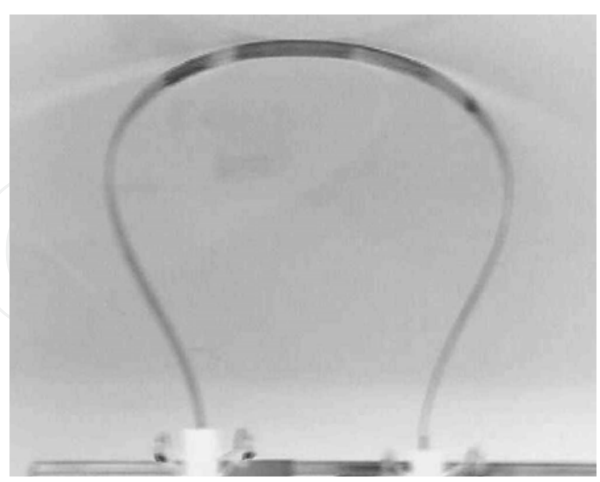

Figure 5.2 Fibre Ribbon Sensitive to Curvature

provide both functions simultaneously, resulting in tactile sensing with a range of over 15 cm. This range is two orders of magnitude larger than the range of traditional tactile sensors. Throughout their 15 cm tactility range, curvature gauge loops generate negligible reaction forces with the impacting body. (Djordjevich et al. 2000)

The range mentioned is on top of the one provided by the elastic bumper on which the optical fibres are mounted (Figure 5.3). Configuration of such an elastic bumper is also monitored by a separate curvature gauge taped along it, making it sensitive to deflection within its entire range of deflection. Instead a strip, this elastic bumper can be a sheet wide enough to cover the entire front surface of the AGV. Importantly, such elastic sheet would be sensitive to its own curvature. (Djordjevich *et al.* 2000)

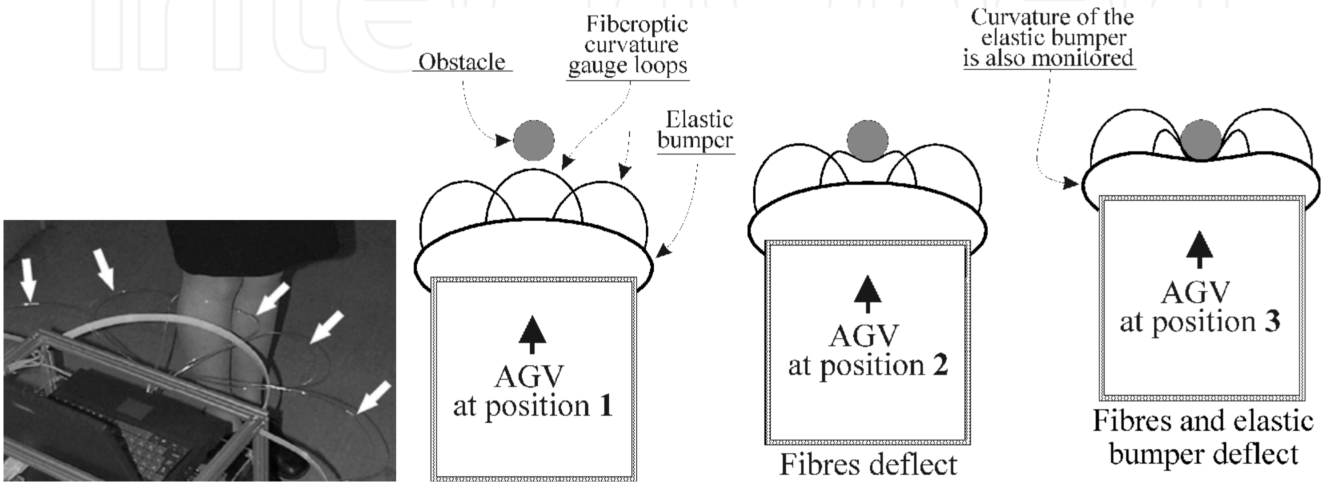

Figure 5.3 The elastic bumper and fibre ribbons are sensitive to curvature

When an unexpected obstacle is detected between the passenger and the AGV (points B in Figures 5.4a and 5.4b), the guidance algorithm is such that the vehicle backs by a predetermined distance (to point A in Figure 5.4) and attempts to go around the obstacle

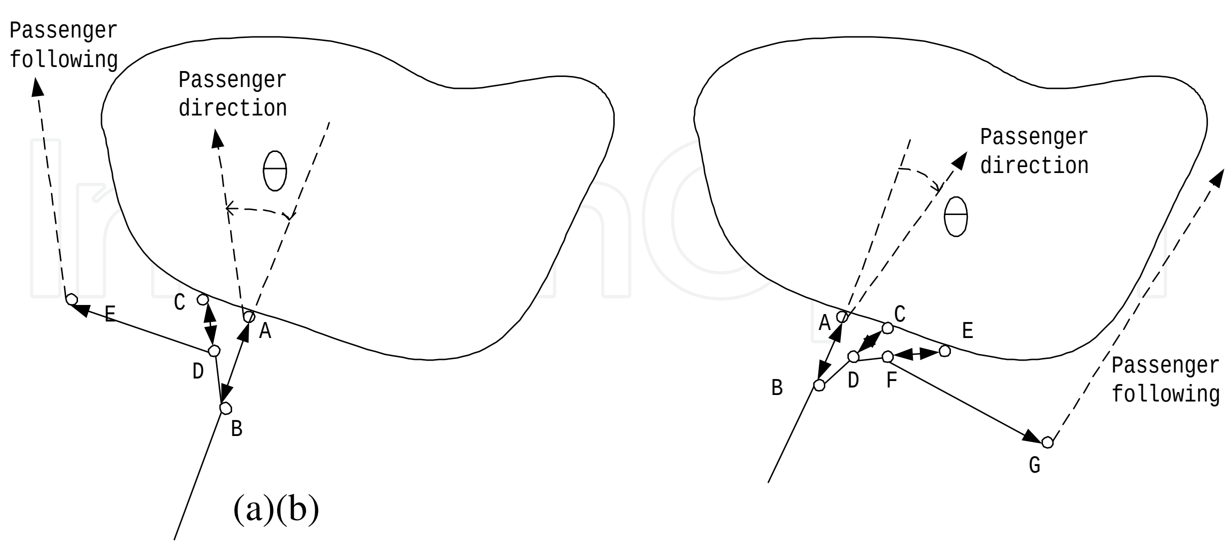

Figure 5.4 Left-hand (a) and Right-hand (b) Obstacle Avoidance Schemes

with the objective of getting back onto the track behind it and continuing further along. Figure 5.4a shows such a manoeuvre in its left-hand version triggered by the deflection of sensors on the right half of the AGV. Deflecting other frontal sensors, whether alone or in a combination with those on the right-hand side of the vehicle, initiates, as the default case, a manoeuvre illustrated in Figure 5.4b. Depending on the passenger's location with respect to the AGV principal direction (the sign and magnitude of angle θ), the two avoidance schemes may be swapped.

6. Ventilation-Duct Inspection Robot

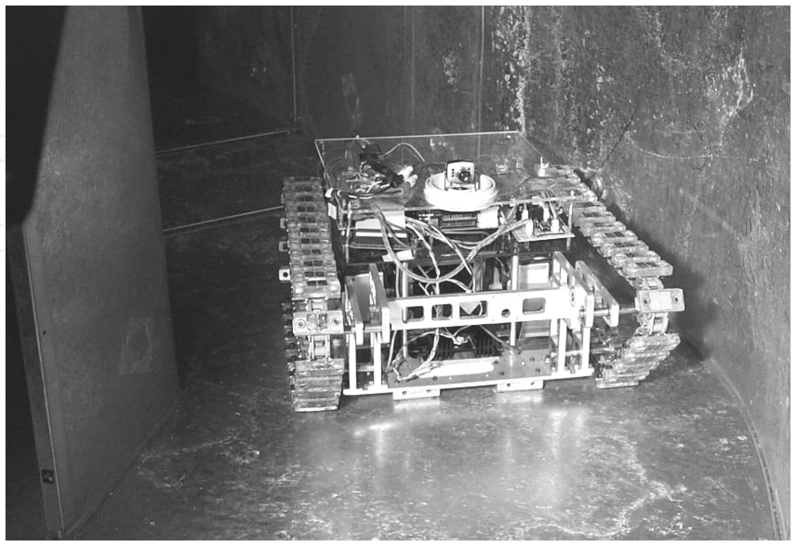

Figure 6.1 Ventilation-duct Inspection Vehicle

A maze of crisscrossing ventilation ducts is a rather common sight in modern high rise commercial and industrial buildings. Their unsightliness apart, a major problem with ventilation ducts is that they enclose often cool and condensate laden environment favourable for the development and spreading of mildew. Mildew irritants represent a serious health hazard for sensitive occupants in the buildings who are left with little choice on how to avoid the exposure or protect themselves. A tele-steerable tracked vehicle capable of navigating through common types of ventilation ducts, whether horizontal, inclined, vertical, or with sharp corners, is shown in Figure 6.1. The main purpose for its development is inspection, although it could easily be adapted to spray fungicides or multi component sealing or rust-proofing agents, or to perform duct cleaning and mechanical repair.

Equipped with a camera, the vehicle relays back to its operator outside the visual internal information about the duct. To allow track adhesion to duct walls while climbing, moving on the sealing, or floor/wall/sealing transitioning, the vehicle has many powerful rare-earth magnets incrusted in its tracks. The tracks are made of flexible plastics for firmer grip on metal sheets. Because the vehicle during the operation is enveloped by the steel sheet metal of the duct acting like the Faraday cage that hampers wireless communication, the vehicle drags its umbilical cord that must be coiled back when reversing the vehicle at the end of the mission.

7. An Intelligent Networking and Automation System for Home and SOHO Environments

The ever increasing desires for improvement in efficiency and comfort for individuals' home and office environments have provided the driving force for the recent development in Home/SOHO (Small Office and Home Office) automation and networking systems (Tso *et al.* 2003). One of the main problems in home/SOHO automation is the wide diversity of technologies, application requirements and limited cost allowance. As a result, it is difficult to use a single network technology to link all the resources together and hence the home/SOHO automation system will need to handle the heterogeneous nature of the home/SOHO network. Moreover, the automation system should be able to add or remove resources in an ad hoc manner in order to make it convenient for users to add or remove home/office devices. Since users of this type of system are usually not experienced in setting up the network for SOHO's devices and resources, the automation system should provide a plug and play feature to avoid any lengthy and complicated configuration process.

A Home/SOHO automation system presented in this Section handles heterogeneous network systems. The application of the UPnP (Universal Plug and Play) open standard makes the network connection of various devices as transparent to the users as possible. The current experimental Home/SOHO system can support Bluetooth wireless network, Lonworks, IR, C-bus, 315MHz, 418MHz and 433MHz ISM band RF, and broadband Internet communication. It is flexible enough to serve as an experimentation platform when developing other Home/SOHO automation technologies.

7.1 Heterogeneous System Architecture

Figure 7.1 illustrates a typical configuration of a heterogeneous Home/SOHO network system. It consists of a number of appliances connected via different networking technologies such as Bluetooth wireless network, Lonworks, CAN Bus, infrared remote control, C-bus, RF, Ethernet network and broadband Internet communication. The home gateway as a central control point of the network is able to communicate with all appliances within this Home/SOHO network environment. As a result, the message exchange between the gateway and the appliances and also the intercommunication between appliances is addressed. Besides, the interoperability between appliances of different manufacturers is also an important issue. In order to address it, a flexible control architecture shown in Figure 7.2 is devised. The architecture is divided into 5 layers: Physical Device Layer, Network Access Layer, Logical Appliance Layer, Common Service Access Layer and User Application Layer. The proposed architecture separates the implementation details of the low-level hardware network from the actual end-user application. This arrangement allows application developers to concentrate on the actual applications rather than on the details of the low-level hardware implementation.

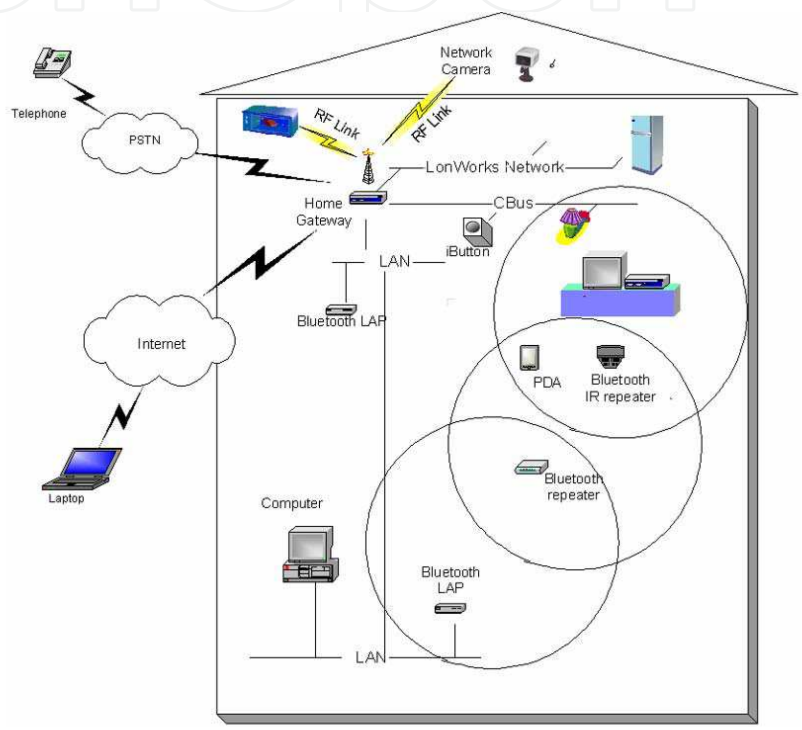

Figure 7.1 A typical heterogeneous Home/SOHO Network System

The Physical Device Layer is the low level driver for communicating with the device. The Network Access Layer provides a unified interface for accessing different network systems. The Logical Appliance Layer provides a unified interface for accessing individual appliance irrespective of its underlying technologies. The Logical Appliance Layer comprises a number of software modules (Control points) for different networking technologies. Irrespective of different networking technologies, all Control Points provide common services to the upper protocol layer, such as automatic discovery of devices, common device access API, event notification etc. The Control Point presents all discovered appliances as logical appliance objects to the Common Service Access Layer and the user applications can access all appliances via the Common Service Access Layer.

The User Application Layer provides the client applications, such as Web browser, WAP browser, Pocket PC application program or tailor-made control console, for the end users to access the resources managed by the system.

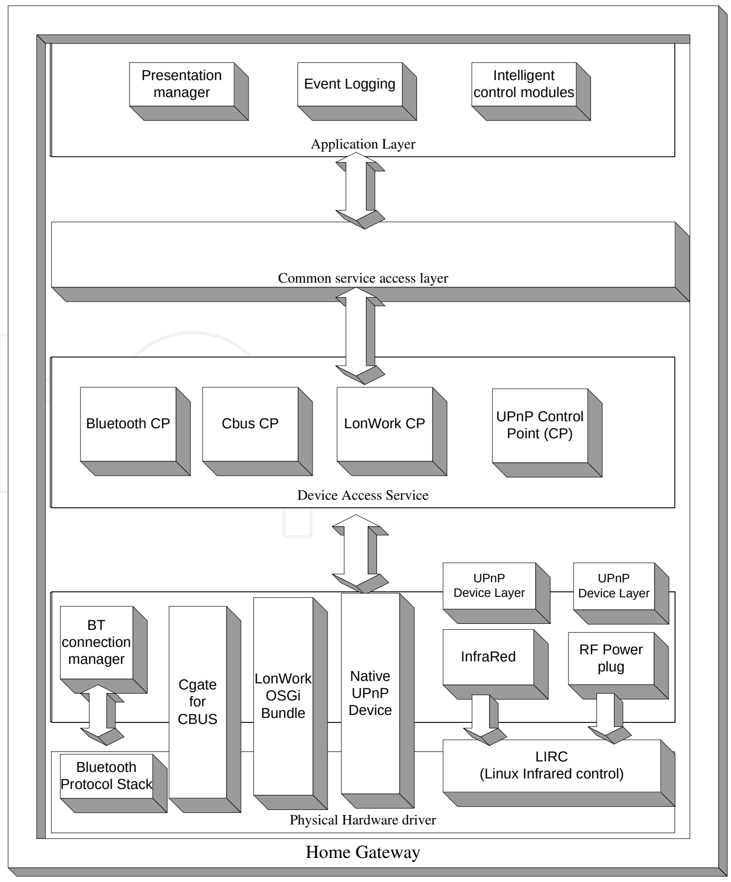

Figure 7.2 System Architecture

7.2 Java-Based Software Implementation to Facilitate Lay Users

The system is implemented on the Linux platform with Java Embedded Server (JES) technology. The Java Embedded Server is an implementation of OSGi architecture. Under the OSGi framework, most of services of the Home gateway are implemented as OSGi 'bundles'. The OSGi framework provides several advantages important for the Home/SOHO gateway, including:

- platform independence;
- service discovery and dependency resolution;
- dynamic service update; and
- sharing of service.

All applications are currently implemented as OSGi bundles under JES, which allows the just-in-time service delivery to the end-user.

User-friendliness is important. Since the end users will not normally be knowledgeable enough to set up a complicated network system for all of the home or office appliances, the whole system should be plug-and-play requiring only simple set up procedures. Hence, the Universal Plug and Play (UPnP) standard has been implemented. It does the features of automatic service discovery, remote access and event notification, which are essential for developing the plug-and-play capability for networking intelligent ad hoc devices. Since UPnP uses standard Internet protocols like TCP/IP, HTTP, XML, SOAP etc, it makes interoperability an inherent feature of the system. For legacy devices, such as IR appliances, additional UPnP bridging software modules are implemented on top of the device drivers in order to make the devices UPnP compliant with the UPnP framework.

Wireless communication is important for the Home/SOHO system because it enables users to add/remove devices from the network dynamically. Bluetooth has certainly attracted worldwide support and a number of home appliance manufacturers, such as Sony, intend to add Bluetooth communication to their future products. Hence, Bluetooth has been adopted as the main wireless communication network. Among the various profiles supported by Bluetooth, Audio/Video Remote Control Profile (AVRCP) is most suitable for the current applications. In this profile, the controller translates the detected user action to the A/V control signal, and then transmits it to a remote Bluetooth device. Two different roles are defined for devices in this profile, a controller (CT) and a target (TG). The CT, such as a personal computer, a PDA, a mobile phone or a remote controller, sends a command to a TG, such as a TV, a headphone or a video player/recorder. Upon receiving a command, the TG responds back to the CT as shown in Figure 7.3.

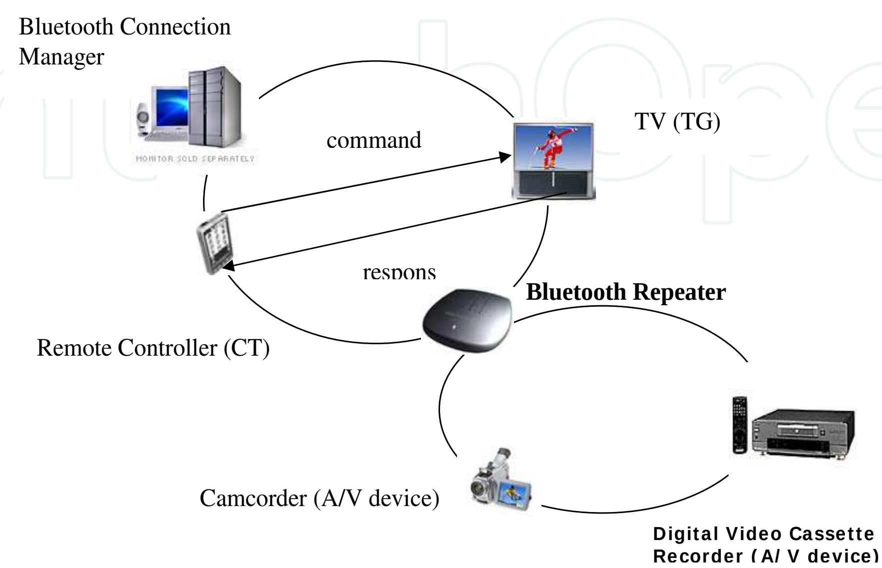

Figure 7.3 Bluetooth home system with AVRCP

Unlike the traditional IR remote controller, this one can support several A/V devices implemented with AVRCP. The communication between CT and various TGs is organised through the Bluetooth's piconet mechanism. In the present system, a Bluetooth connection manager has been developed and implemented with AVRCP. All the A/V devices within the coverage area are visible to this manager. It can control all the devices from the user input and the knowledge captured based on the user habits. Moreover, a Bluetooth repeater with AVRCP has also been developed to extend the coverage area of the whole system. This repeater keeps a list of all the A/V devices and sends the list to the connection manager periodically. The limited coverage area can be expanded by attaching more Bluetooth repeaters to cover a larger area as shown in Figure 7.3. The advantages of using this profile are that all the Bluetooth A/V devices have a standardised model, which makes the devices inherently interoperable, and also future A/V devices with AVRCP could be operated without major modifications.
The AVRCP communication among all devices and TCs is inherently bidirectional. This two-way communication network constitutes the fundamental requirement for development of an intelligent control system. To illustrate this application, an intelligent control module will be described in next section.

7.3 Inclusion of an Intelligent Control Module

The main aim of the intelligent control module is to automate daily operations of the system so that the system execution is more intelligent and pleasing to users. There are two main components of the module: knowledge-capturing and pattern recognition. As mentioned in section 7.2, all communication among devices and TCs are bidirectional.

Therefore, all user inputs to TCs and devices can be recorded. This information is basically an unorganised knowledge requiring pattern recognition to yield the rule description. The proposed intelligent module makes use of knowledge for intelligent operation and enhanced automation. Knowledge, in general, is either pre-installed or run-time captured. While the former source is described by commonly accepted rules, the latter source is initially empty and must be captured dynamically.
For example, a concentration of the indoor carbon dioxide (CO_2) exceeding 1000 PPM is harmful to humans and calls for fresh air intake. Therefore, a ventilation fan equipped with a CO_2 sensor is pre-programmed to operate based on this pre-installed rule. There may be further consequences to such an automated action as the indoor temperature might be altered in the process unintentionally. Because the user is then likely to raise the setting of the air-conditioning system, his/her behaviour would be recorded by the intelligent control module, thus dynamically capturing knowledge (or more precisely, the rule). The captured information is binary in nature and it can be represented in the form of a truth table. Pattern recognition technique is applied to build up the truth table.
Consider a typical truth-table data in Table 7.1 captured by the daily operation of a home/SOHO scenario. The events represented are: (1) an alarm clock goes on and then off; (2) bedroom light is switched on; (3) bathroom light is switched on; (4) hot water is used for shower. Some associated information, such as the time and day of the week following a predefined triggering event (the alarm clock in this case), is also recorded. This is then compared to two subsequently recorded patterns. Simple AND operation is carried out for each entry so that the event relations are extracted. In this case, the extracted rule is that when the alarm of the clock is switched off, the bedroom light should is switched on, then the bathroom light and water heater. The function of the associated information such as the time and day of the week is to restrict and narrow the record comparison.

Time index	Alarm clock ON	Bed room light ON	Bath room light ON	Water heater ON	•	Exhaust fan ON	A/C Power raised
1	1	0	0	0	•	0	0
2	0	0	0	0	•	0	0
3	0	1	0	0	•	0	0
4	0	1	1	0	•	0	0
5	0	1	1	1	•	0	0
•	•	•	•	•	•	0	0
•	•	•	•	•	•	1	0
•	•	•	•	•	•	1	1
•	•	•	•	•	•	•	•

Table 7.1. A typical example of captured user behaviour information

7.4 Presentation Manager

In the application layer, the intelligent control module is developed such that all devices are discovered and connected in the system as mentioned in section 7.3. Another important application in this layer is the user interface (Presentation manager) shown in Figure 7.2. Different features of user interface can be summarized as:

a) regular web browsers on PCs using HTML (HyperText Markup Language) –provide a very common means of controlling devices remotely from anywhere in the world;
b) web browsers on PDA using HTML and web enabled cellular phones using WML (Wireless Markup Language) – provide mobile solutions for users to control devices with limited functions;
c) Java client for systems with installed JVM (Java Virtual Machine) – requires that users pre-install a client application on the client machine (Java native client applications can generally provide an interface with faster response, and enable that voice technology be embedded in the Java client applications);
d) voice enabled bundle in server – all devices can be controlled through a microphone from the server.

Overall, the multi-layer software architecture applied and Java based implementation provides a flexible platform for developing ad hoc heterogeneous network system for intelligent devices. The two-way communication feature among all components (TC or TG) constitutes the infrastructure for developing an intelligent control module. Moreover, it allows the development of the user-friendly and reliable interface so that the status of all devices could be monitored by the user even remotely.

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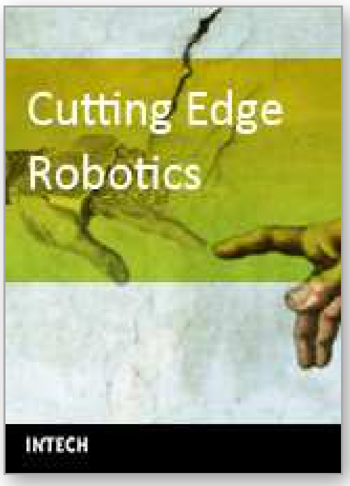

Cutting Edge Robotics

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This book is the result of inspirations and contributions from many researchers worldwide. It presents a collection of wide range research results of robotics scientific community. Various aspects of current research in robotics area are explored and discussed. The book begins with researches in robot modelling & design, in which different approaches in kinematical, dynamical and other design issues of mobile robots are discussed. Second chapter deals with various sensor systems, but the major part of the chapter is devoted to robotic vision systems. Chapter III is devoted to robot navigation and presents different navigation architectures. The chapter IV is devoted to research on adaptive and learning systems in mobile robots area. The chapter V speaks about different application areas of multi-robot systems. Other emerging field is discussed in chapter VI - the human- robot interaction. Chapter VII gives a great tutorial on legged robot systems and one research overview on design of a humanoid robot.The different examples of service robots are showed in chapter VIII. Chapter IX is oriented to industrial robots, i.e. robot manipulators. Different mechatronic systems oriented on robotics are explored in the last chapter of the book.