DEVELOPMENT OF WIRELESS MECHANISM TO REDUCE WIRING COMPLEXITIES OF ROBOT MANIPULATOR

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Wires in the robotics system are used to connect between controllers and the DC power sources; these controllers include the microcontrollers, sensors and actuators. These wires that pass through the robot manipulators unnecessarily induce complexities which inhibit the manipulator flexibility. Wiring complexities consists of the control wires which are used to connect between controllers, and power source wires which conduct the current to the controller components. This research aims to reduce these wires complexities. Instead of control wires, a wireless voltage regulatory (WVR) module was developed. The WVR has the ability to form Bluetooth network between controllers integrated with an adaptive voltage regulation. The adaptive voltage regulation purpose is to control the DC motors or any other devices that require voltage regulation in the control system. It was attained by applying the fuzzy control. Instead of Power source wires, a modification for the translational and rotational mechanisms design is proposed to conduct the DC power wirelessly. A physical model demonstrating the developed wireless module and the proposed mechanical modification was built, and its performance is presented. The contribution of this work includes enhancement of the robots manipulator flexibility, functionalities and applications by reducing wires complexities.
CHAPTER 1

INTRODUCTION

Robotics nowadays is very advanced and a major contributor to major applications in fields such as industrial, military, medical and public services. Robotics field need a lot of research efforts due to its significance, thus its development is perpetual to fulfill the life requirements. The system of robotics has lot of challenges and several contribution areas. Robotics can be considered from different perspectives, and can be divided into main components as follows:

- Manipulator mechanisms and actuators for making the robot move through its environment including the physical organization of motors, belts and gears.
- Controllers which comprise of a computer or collection of computers for controlling the robot.
- Collection of sensors with which the robot gathers feedback information concerning its environment to the controllers.
1.1 Overview

There are several methods of communication between the control system components (controller, sensors and actuators), identifying these components depends on the functions and the applications of robots.

The current research specifically focuses on the communication among several controllers in the robot control system, where each controller has to connect to a group of sensors and actuators. This integration among controllers is usually carried out through wiring system connections.

The wire system in robot consists of input signals, output signals and power source. These wires cause wiring complexity in the robot system. In the current robotics applications it was found that the wires still represent a problem which affects the mobility and flexibility of robots manipulator. Wires induce restriction on the functionality development especially on transformable mobile robots, thus eliminating or reducing constraints which affect the transforming operation is desirable.

The wires complexities can be divided into two types. Firstly, Control wires that pass the input and output signals from the controller (microcontroller) to the actuators, or from the sensors to the microcontroller. Secondly, the power source wires which supply the control system components by the DC power. Figure 1.1 illustrates the wiring complexities of a typical manipulator.
1.2 Problem Statements

The problems which encounter us due to wiring complexities specifically in robotics application are;

1. Problems associated with wiring connections such as Installation problems,
2. Signal hysteresis due to weak fixation.
4. Inflexible modification.

Also, problems of the manipulator mechanisms restrictions due to wiring connections include;

- Mobility and flexibility of the robot mechanisms.
- Deployment of Sensors and actuators on the robot manipulator.

Therefore this research work is coming out by a solution that can aid in reducing the wiring complexities.
1.3 Research contribution

The contribution of this research is to reduce the wiring complexities (control and power wires) while enhancing the communication between the controllers of the robot manipulator. This enhancement is achieved by utilizing advanced ways such as wireless technology and applying the suitable modification and improvements to the mechanical system.

1.4 Objectives

The objectives of this work are as follows;

i. Develop wireless network between controllers (sensors and actuators) replacing control wires.

ii. Modifying the Rotational and Translational mechanisms to enable transferring the DC power source replacing power wires.

1.5 Scope of Work

This research is a combination between mechanical, electronics and control fields known by mechatronics. The scope of the work sequence as follow;
1. Study
   i. The available wireless technologies for achieving the communication between controllers (sensors/actuators) instead of wires.
   ii. The robot manipulator movements and the possibility of the mechanisms in conducting DC power instead of wires.

2. Develop
   i. The communication system between controllers (sensors/actuators) using the Bluetooth technology.
   ii. The Rotational and Translational movements to transfer DC power.

3. Build The Physical Model
   i. Mechanical: fabricating the robot modified mechanisms.
   ii. Control: building the wireless control circuit.

4. Verify
   Show the performance of the system, and its behavior in both sides the mechanical and control.

1.6 Thesis Organization

The rest of thesis is organized as follow:
Chapter Two gives a review of the literatures which were relevant or contributes in the research work. This included review of the wireless technologies and its implementations in the robotics field, its effect on the mobility and flexibility of the robot and also the importance of programming interface in such applications.
Chapter Three discusses the methodology of this research which consists of identifying the problem and solution to develop the robot wireless mechanism.

Chapter Four demonstrates the experimental setup and test which include installation of the wireless communication between controllers and the developed control module. As well as discussing the performance of the system.

Chapter Five explain and discuss the proposed modification to the robot manipulator mechanisms to transfer DC power.

Chapter Six gives the research work conclusion, its contribution and recommendations for future work.
CHAPTER 2

LITERATURE REVIEW

This chapter provides a review on the main subjects which are involved in the research focus. This subjects such as wireless sensor network (WSN), wireless sensor actuator network (WSAN), wireless standards, network topologies and the application programming interface (API). Moreover it represents some of the implementations and application which are relevant, showing how it supports the current research work in some points for achieving the research aim and objectives.

2.1 Wireless Sensor Networks (WSNs)

The huge growth of wireless communications in recent years is mostly due to new connectivity demands and advances in technology development of low power Complementary Metal-Oxide-Semiconductor (CMOS) transceivers. An example of the new demands is the increasing exchange of data in Internet services which has led to the deployment of wireless networks for data transmissions characterized by the need of high data throughput (Gutierrez, 2001). A typical example of these networks is
represented by Wireless Local Area Networks (WLANs) IEEE Std 802.11/a/b
(Wickelgren, 1996). Wireless Personal Area Networks (WPANs) usually supporting
links up to 10 m in length, are another emblematic example. One of the best known
WPANs is Bluetooth which is based on IEEE Std 802.15.1 (IEEE-Computer-Society
2006). On the other hand there are wireless network applications requiring low data
throughput such as home automation and health monitoring (Estrin et al., 2001).

WSN users are entities outside the WSN, who interact with WSNs through the gateway
nodes using client devices. Unlike traditional wired or wireless networks, WSNs are
data-centric (Stankovic et al., 2003), which means that WSN users are not necessarily
interested in the state of a single node. Instead, they want to query data based on
attributes like location, area, and data content (Jari et al., 2006).

Since most of these low-data-rate applications involve some form of sensing and
actuation, networks supporting them have been designated as wireless sensor networks
due to the length of the name “Wireless Sensor & Actuator Networks” (Gutierrez,
2001) (Gutierrez et al., 2004). It is important to distinguish WSNs from Mobile Ad-hoc
Networks (MANETs). MANETs share some characteristics with WSNs such an ad-hoc
networking and low power consumption but they are different in the sense that they
pursue different research goals (Karl & Willig, 2005).

2.2 Wireless Sensor/Actuator Networks (WSAN)

Significant effort has been made in research and development of WSNs in recent years.
Tremendous advancements have been achieved with respect to deployment,
localization, power control, topology control, routing, distributed signal processing, and
security (Heidemann & Govindan, 2005).
WSANs are a relatively new research area with limited progress (Akyildiz & Kasimoglu, 2004) serving as the backbone of control applications, WSANs will enable an unprecedented degree of distributed and mobile control (Rezgui & Eltoweissy, 2007). However, the unreliability of wireless communications and the real-time requirements of control applications raise great challenges for WSAN design.

Recent advances in pervasive computing, communication and sensing technologies are leading to the emergence of wireless sensor/actuator networks (WSANs). A WSAN is a distributed system of sensor nodes and actuator nodes that are interconnected over wireless links. Sensors gather information about the physical world, for example the environment or physical systems, and transmit the collected data to controllers/actuators through single-hop or multi-hop communications. From the received information, the controllers/actuators perform actions to change the behavior of the environment or physical systems. Consequently, WSANs have the ability to change the physical world; the advent of which has the potential to revolutionarily promote existing control applications. It can be envisioned that WSANs will become the backbone of many control applications enabling an unprecedented degree of distributed control.

The use of WSANs in control applications has many advantages compared to wired solutions, which are dominant at the moment (Xia et al., 2007). For instance, WSANs allow more flexible installation and maintenance, fully mobile operation, and monitoring and control of equipments in hazardous and previously difficult-to-access environments. Important factor of WSANs that instigates the easy deployment despite many advantages, WSANs also raise challenges for control applications (Li, 2006).

Control technology utilizing wired sensors and actuators is well established. The advent of small, lower energy, intelligent wireless sensing and actuation devices has the potential to significantly expand and enhance existing control applications. Compared to their hard-wired counterpart, wireless sensor actuator networks offer several significant advantages.
The envisaged flexibility and ease of deployment of wireless sensor networks are some of the reasons for its numerous applications, such as, smart home environment, meetings/conferencing, inventory, indoor location and tracking, industrial sensors and several military applications. Furthermore, it is envisaged that such distributed sensor systems would have actuation capabilities to physically perform tasks and thereby increasing further their usefulness (Seah, W.K.G et al., 2006).

The wireless approach shows many advantages but also has some disadvantages with respect to wiring networks. Mobility is clearly one of the major advantages of wireless with respect to cabled devices, which require plugging (Mathiesen et al., 2005). In combination with the unique characteristics of WSANs, control applications pose the following main challenges associated with the design of WSANs.

**Reliability**: From the control perspective, packet loss degrades control performance and even causes system instability. Because practical control applications can only tolerate occasional packet losses with a certain upper bound of allowable packet loss rate, WSAN design should minimize the occurrence of packet losses as much as possible. Ideally, every packet should be transmitted successfully from the source to the destination without loss. However, due to many factors such as low-power radio communication, variable transmit power, multi-hop transmission, noise, radio interference, and node mobility, packet loss cannot be completely avoided in WSANs. The challenge then becomes how to improve the reliability of the network system in the presence of packet loss.

**Real-time constraint**: Control systems are inherently real-time systems in the sense that control actions must be performed on the physical systems by their deadlines. It is worth mentioning that real-time does not necessarily mean ‘fast’. For real-time control applications, both delay and its jitter should be limited and predictable in favor of control performance improvement. However, the use of dynamic routing protocols and random MAC protocols, as well as the mobility of nodes, makes the WSAN-induced
delay time-varying and unpredictable. The challenge here is how to guarantee the delay is sufficiently small and deterministic with small jitter so that it will not significantly degrade the control performance.

2.3 WSNs and WSAN Applications

An overview of the most relevant applications for WSNs and WSANs is given below. Robotics applications: Robots are being paid much attention to perform difficult tasks that cannot be done by human beings (Ozaki et al., 1994); (Suzuki & Sawai, 2004). Although each robot is equipped with sensors and actuators, constructing a flexible wireless sensor network is possible by mainly utilizing sensing capability.

**Industrial Control and Monitoring:** Significant cost savings may be achieved with the use of inexpensive wireless sensors/actuators since sensors and actuators in industrial plants are often relatively inexpensive when compared with the cost of installed cable to communicate them. Examples include industrial safety, monitoring and control of rotating and/or moving machinery and heating, ventilating and air conditioning (HVAC) of buildings.

**Home Automation and Consumer Electronics:** Most of industrial applications have parallels in the home (Callaway et al., 2002), for example a home HVAC system. Other applications include security systems, commercial lighting, PC peripherals and computer enhanced toys. Another interesting application is the use of location-aware capabilities of WSNs for consumer related activities such as tourism and shopping (Asthana & Drzyzanowski, 1994)
Security and Military Sensing: Thanks to WSN components specific characteristics such as, small sizes, unobtrusive and distributed mesh topologies; it is possible to deploy camouflaged sensors to resemble for example native rock or other nature bodies. The intrinsic resilient nature of WSNs makes them difficult to destroy in battle (Hewish, 2001).

Asset Tracking and Supply Chain Management: Warehouses require efficient organization to be able to manage the stored items. With the help of WSNs item locations can be accurately identified. Tracking is also a field that could be benefited by the use of WSNs. One tracking example is the Authenticated Tracking and Monitoring System (ATMS) (Schoeneman & Sorokowski, 1997).

Intelligent Agriculture and Environmental Sensing: WSNs may aid farmers gathering information about soil moisture, temperature, received sunshine and other related parameters. Vineyards are one of the first targeted markets for these kinds of applications. Environmental sensing may be achieved with ultra low-power WSNs providing information about atmosphere contaminants, noise pollution and so on.

Health Monitoring: Health monitoring must be understood as monitoring of non-life-critical health information, to differentiate it from medical telemetry (Gutierrez, 2001). There are two principal applications in health monitoring, athletic performance monitoring and home health monitoring.
2.4 Wireless Technologies

In these days we can identify various wireless standards technologies, such as WLAN, Bluetooth and Zigbee, each of these developed standards have its own strengths and weaknesses.

The basic features and specifications of the various wireless standards in a kind of comparison are shown in table 2.1.

Several researchers discussed the standardization, regulation (Park & Rappaport, 2007), development issues associated with short-range wireless technologies for next-generation personal area networks (PANs) (Davies, 2002), the physical layer (PHY) specifications and MAC protocols for these technologies (IEEE 802.15: WG for WPAN, 2006), the coexistence of the wireless technologies (Ophir et al., 2004), the potential reliability and the degree of subjectivity to interference (Chadwick, 2007).

There are some other comparable factors related to the communication field can be reviewed at (Ferro & Potorti, 2004) (Moeckel et al., 2006) and (Lee et al., 2007).

Whilst power consumption is one of the research main concerns, a comprehensive study on different wireless standards showed that Bluetooth and Zigbee consume much less power than the other standards (Mathiesen et al., 2005); (Johansson et al., 2002).

Regarding to the power consumption and its importance especially in embedded control systems such as microcontrollers, the core of our implemented applications, the Bluetooth and Zigbee were the promoted standards for these wireless control system networks. So there are important basics have to be understood.

Bluetooth and Zigbee are two similar technologies in terms of use of short range radio links and ad-hoc support; however, there are several differences between these two technologies.
### Table 2.1 Wireless Standards Comparison

<table>
<thead>
<tr>
<th>Factors</th>
<th>Bluetooth</th>
<th>WLAN IEEE80211</th>
<th>ZigBee</th>
</tr>
</thead>
<tbody>
<tr>
<td>Range</td>
<td>10m-100m</td>
<td>100m</td>
<td>30-100m</td>
</tr>
<tr>
<td>Associated Standard</td>
<td>IEEE 802.15.1</td>
<td>IEEE 802.11a/b/g</td>
<td>IEEE 802.15.4</td>
</tr>
<tr>
<td>Frequency Bands</td>
<td>2.4 GHz</td>
<td>2.4 GHz or 5 GHz</td>
<td>868 MHz, 915MHz, 2.4 GHz</td>
</tr>
<tr>
<td>Physical Layer</td>
<td>FHSS</td>
<td>DSSS or OFDM</td>
<td>DSSS</td>
</tr>
<tr>
<td>Maximal Gross Data Rate</td>
<td>1 Mbps</td>
<td>5.5/11/54 Mbps</td>
<td>20/40/250 kbps</td>
</tr>
<tr>
<td>Network topology</td>
<td>Star, piconet, scatternet</td>
<td>Star</td>
<td>Star, mesh, cluster-tree</td>
</tr>
<tr>
<td>Maximal Number of Nodes</td>
<td>7 slaves in a piconet</td>
<td>32 APs (Access Point)</td>
<td>65'000</td>
</tr>
<tr>
<td>Expected Main Use</td>
<td>Cable replacement</td>
<td>Wireless Ethernet, mobile office</td>
<td>Monitoring and control, autonomous devices</td>
</tr>
</tbody>
</table>

In general, both Bluetooth and Zigbee systems operate globally in the ISM-band (2.5 GHz) worldwide. In addition, Zigbee-compliant products can operate in the unlicensed hands of 915 MHz (South and North America) and 868 MHz in Europe. Likewise, the Bluetooth can operate at 915 MHz and 868 MHz. Both systems use the Spread Spectrum (SS) technology.

The distinction is, however, that the Bluetooth uses the Frequency-Hopping Spread Spectrum (FHSS) technique and the ZigBee is based on Direct Sequence Spread Spectrum (DSSS). These refer to the two underlying schemes of the Code Division Multiplexing Access (CDMA) method. The FHSS sends packets corresponding to an output set of one-at-a-time discrete frequencies randomly hopped and spreading over a wide band. The DSSS on the other band uses a digital spreading function representing a pseudorandom (PN) digital pulse train ("chip code") for each transmission. The sequence of frequency hopping of the FHSS is also decided by a PN code (Neelakanta & Dighe, 2003).
Bluetooth and Zigbee are not competing technologies but solutions for two different application areas. Bluetooth is intended for personal devices such as cell phones and PDAs requiring transmission of files and larger data applications with a star master/slave topology. On the other hand Zigbee is intended for low duty cycle devices with short message applications supporting different network topologies (Castano, 2006).

2.4.1 Bluetooth Basics

In 1994 Ericsson Mobile Communications started to investigate alternatives to connect mobile phones with external accessories. The result of these investigations led to the first Bluetooth specification designated as Bluetooth 1.0. Bluetooth uses radio links for exchange of data and speech between mobile phones, headsets and computing devices.

The technology is named after Harald Blatand (Blatand is Danish for Bluetooth); Harald was a Danish Viking king who unified Denmark and Norway. Since Bluetooth was expected to unify the telecommunications and computing industries, the name seemed to fit in. Moreover the Bluetooth Special Interest Group (SIG) formed by companies cooperating to promote and define the Bluetooth specification was formed. Improvements have been added to newer versions of the specification like the latest Bluetooth v2.0 supporting Enhanced Data Rate (EDR) and Adaptive Frequency Hop Spread Spectrum (A-FHSS).

Bluetooth is a RF wireless technology with many components and abstraction layers. Bluetooth is originally intended to replace cable(s) connecting portable and/or fixed electronic devices such as mobile phone handsets, headsets, and portable computers. Bluetooth standard as wireless interface allows benefiting from later developments and
improvements of this technology. It can easily communicate with other Bluetooth
devices like Bluetooth dongles or Bluetooth interfaces that can be found in PCs, mobile
phones and PDAs, the popularity of Bluetooth make it possible to buy Bluetooth chips
for low price (Moeckel et al., 2006).
Bluetooth is an energy-efficient communication technology and is therefore ideal for
the battery powered (Witkowski & Rückert, 2005).

As a conclusion, the basic features of Bluetooth are low power, low cost and short-
range; Short range refers to a personal operating space or Personal Area Network
(PAN) (typically 10 m). The main purpose is that devices will communicate seamlessly
supporting Asynchronous Connection Less (ACL) and Synchronous Connection
Oriented (SCO) links for data and voice respectively. The Bluetooth specification is
open and global, detailing the complete system from the PHY layer up to the APP
layer. Bluetooth operates in the globally available, Medical (ISM) band and license-
free Industrial Scientific at 2.4 GHz; this has the advantage that no fees have to be paid
for sending data via Bluetooth. Mature versions of the Bluetooth specification used a
Gaussian Frequency Shift Keying (GFSK) modulation scheme signaling data at 1
Mega-symbol per second obtaining the maximum available channel bandwidth (1
MHz). However the maximum achievable throughput with specification 1.0b, 1.1 and
1.2 is 723.2 Kbps as described in equation 2.1.(Krammer et al., 2002).

\[
\text{Throughput} = \frac{\text{Max} \times \text{User Payload}}{6.625 \mu S} \\
= \frac{339 \text{ Bytes} \times 8 \text{bits}}{6.625 \mu S} = 723.2 \text{ Kbps}
\] (2.1)

The newest version (v2.0 + EDR) on the other hand, increases raw data-rates up to 2
Mbps and 3 Mbps allowing users to run several links concurrently by enabling
sufficient bandwidth. The increase in raw data rate has other advantages apart from the
just mentioned, transceivers need only to remain fully active for about a third of the
time (for transmitting the same amount of data) and thereby battery life is prolonged.
2.4.2 Bluetooth Network Topology

Topologies are important to design the wireless network, studying the difference between each topology aid in forming an efficient network. The networking knowledge of the wireless devices leads to the perfect implementations. A miss configured network can result in a waste of time and energy as well as a lot of troubleshooting methods to resolve the issue. Therefore the basic understanding of the network topologies and network devices is a must to build a good network.

Bluetooth supports a simple star topology known as piconet with one master device and seven active slaves. Another supported topology is referred to as scatternet where several piconets are interconnected (Bray & Sturman, 2002).

Piconets and scatternet

Bluetooth personal area networks, also known as piconets, consist of one master and up to seven active slave devices. A Bluetooth piconet is depicted in Figure 2.1. An additional 255 devices can be connected to the master as long as they are in park mode. The park mode in the same manner a sleeping mode, the main advantages for using Park mode are that it leads to reduced power consumption, allows more than seven devices to be connected to a master, and gives more time for the parked slave to participate on different piconet(s). Within a piconet, each slave is attached to the master via a physical channel. Each of these channels is divided into slots. Packets travelling between the master and the slave are placed into these slots. Physical channels are not created between slaves. All packet transfers are managed by the master device. The master sequentially polls each device to see if it requires service. The master is also responsible for synchronizing all devices to ensure consistent timing.

A device can join a piconet in one of two ways. First, a Bluetooth device can enter an inquiry state to discover other Bluetooth devices. Within this inquiry, information is provided about the types of services needed. Bluetooth devices offering one or more of
the requested services, and that are within the broadcast range, will respond if in
discovery mode. The discovery mode means that the device is able to be seen
(discovered) by other Bluetooth devices. The process used to establish a channel
between one or more of the responding devices depends on the security mode used,
there are three levels of security for Bluetooth access between two devices can be
reviewed at (Bluetooth-SIG, 2001).

Secondly, a master searches for devices within range. If one is discovered, it is
automatically added to the piconet in accordance with security measures in place on
one or both of the devices.

Otherwise, two or more piconets can potentially connect to create a scatternet (Castano
et al., 2003); the main difference from a piconet is the existence of more than one
master in the network. This scatternet formed by a slave device has to act as a master in
another piconet or by using a slave device as a bridge between the two piconets as
shown in Figure 2.2.

![Figure 2.1 Piconnet Network Topology](image)
2.4.3 Zigbee Basics

Zigbee is a new wireless technology included in the WPANs scope (Lin et al., 2007). As Bluetooth, Zigbee is a short-range wireless networking technology where little or no infrastructure is required (no network setups and no APIs) providing ubiquitous, untethered, short-range communications. Its main objective is to enable low cost, low power, reliable devices for monitoring and control purposes.

The Zigbee specification provides a platform for implementation of wireless networked devices. Moreover the specification defines the network and stack models providing the framework to allow a separation of concerns for the specification, design and implementation of Zigbee devices. The IEEE Std 802.15.4 is property of the Institute of Electrical and Electronics Engineers (IEEE) and is part of the IEEE Std 802.15 working-group. This working group is in charge of the development of WPANs standards. The first result of the group was the IEEE Std 802.15.1 commonly known as Bluetooth, which is focused on cable replacement for consumer electronic devices. The
second (IEEE Std 802.15.3) focuses on high-speed WPANs. Finally the third standard (IEEE Std 802.15.4) was defined as a standard to provide ultra-low complexity, low-cost, and extremely low-power wireless connectivity for inexpensive and portable devices. In the case of IEEE Std 802.15.4 the consortium responsible for the development of the NWK and APP layers, and profiles is called Zigbee Alliance. The Zigbee Alliance is a trademark property of Phillips Corporation. Although the current trend in wireless networking is to provide higher data-rates and QoS, Zigbee is intended for low cost and low power short-range communications.

2.4.4 Zigbee Network

There are three topologies for forming a network for the Zigbee wireless standard; star, Mesh and Tree topologies (Zigbee-standards-organization, 2005); (Gutierrez et al., 2004), which basically consists of three nodes; PAN (Personal Area Network) Coordinator, Full Function Device (Router) and Reduced Function Device (End device).

The Coordinator is the device which forms the root of the network, and is the device that started the network originally. While the Full Function Device can act as an intermediate router, passing on data from other device, and the Reduced Function Device contains just enough functionality to talk to the parent node (either the coordinator or a router); it cannot relay data from other devices.

Star Topology
This is the basic topology and consists of a master which is the PAN coordinator; the remaining devices are slaves and connected as Figure. 2.3 depict. The main advantages of this topology are the low latencies (2 hops maximum route path) and the ease of the
routing algorithm. A drawback of this topology is the fact that all devices must be inside the PAN coordinator range.

![Star Network Topology](image)

*Figure 2.3* Star Network Topology.

**Tree Topology**

In this topology several devices may be connected to a single parent device but they can be connected to several children as Figure 2.3 illustrates. In this topology the coordinator is only responsible for starting the network and choosing certain network parameters but the network may be extended through the use of routers.

For example in Figure 2.4 the device with address 1 is child of the PAN coordinator and parent of device 3, device 1 has also 3 grandchildren with addresses 4, 5 and 6 respectively. The routing algorithm must be more advanced than in a star topology network to support multi-hop routing but still the use of a tree structure simplifies the routing algorithm reducing it to a hierarchical routing strategy. For example in Figure 2.3 all devices with addresses that are equal or higher than 3 are always routed via device 1 from the PAN coordinator.
Mesh Topology

This topology is possible when using mesh networks, in a mesh network a device can connect with any other device in its range. As the number of devices grows in a network it also increases the memory requirements to save addresses in the routing tables. The network can be also extended by the use of routers as Figure 2.5 illustrates. The routing algorithm enables exchange of data between any pair of network devices allowing multiple routes. In this case the routing algorithm is more complex and cannot be reduced to a hierarchical strategy as it happened with tree topologies.
2.4.5 Why Bluetooth

Bluetooth is the best choice when developing wireless sensor networks that need a good tradeoff between power consumption and data rate as well as for autonomous robots that need a flexible and powerful communication infrastructure while being powered from a limited source like a battery (Ferro & Potorti, 2004).

There are some reasons justifying using the Bluetooth technology rather than the others; (1) Implementations of the latest Bluetooth standard 2.0 reported power consumptions of more than 10 times less than for WLAN. That is why Bluetooth is very interesting for embedded systems that are battery powered and therefore have limited energy resources.
(2) Latest BT implementations report communications speeds of up to 3Mbit/s, already the former BT standard 1.2 supports data rates of up to 600kbit/s and could provide wireless serial links with a baud rate of about 115200 baud. That is why Bluetooth is much more applicable to robotics than e.g. Zigbee which currently only supports data rates of 20-250 kbit/s.

(3) Bluetooth is using a very robust communication protocol called Frequency Hopping. This allows BT networks to operate reliably in noisy environments and in parallel to other wireless communication networks.

(4) BT devices do not have to be in the visual range of each other to support a wireless link compared with Infrared which have to be in the same line.

(5) The Bluetooth standard tries to support users by providing three different classes of BT devices that provide communication ranges from 10m to 100m and consume a 1mW to 100mW of power, respectively.

2.5 Application Programming Interface (API)

In computer science, the Application Programming Interface (API) is an interface defining the ways by which an application program may request services from libraries and/or operating systems. An API determines the vocabulary and calling conventions the programmer should employ to use the services. It may include specifications for routines, data structures, object classes and protocols used to communicate between the requesting software and the library (Trimintzios et al., 2006).

The purpose of producing a networking API is to cope with the complexity of the underlying network from the application developer (Davis, 1996). Thus the developer does not have to become an expert in the underlying protocols and this means that