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Data transfer for smart clothing: requirements and potential technologies

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10.1 Introduction

Miniaturisation of electronic components has made it possible to build small portable and handheld computer devices that can be carried almost anywhere and at any time. As a result, smaller and lighter devices having high processing capacity are available on the market. This equipment is becoming more wearable since components can be easily hidden inside clothing or embedded in a handbag, for example, and carried for long periods.

A wearable computer is a miniaturised version of a desktop computer that is carried during use. Consequently, a wearable computer is a mobile, fully functional, self-powered and self-contained computer.[1,2] The basic difference from desktop computers is the type of a user interface (UI), since mobility sets new requirements for usability. Wearable computers are intended for general data processing tasks, similar to their desktop counterparts. Basically, the use of the computer is moved to the actual surroundings of everyday life.

Another approach in wearable electronics is smart clothing. Smart clothes emphasise the importance of clothing while designing and implementing the wearable systems. Smart clothing applications are constructed using functional modules or intelligent fabric materials that are placed on or inside ordinary clothes.[3] The functional modules can be non-electrical, e.g. an integrated first aid kit, but in our view they are considered to be electronics. Electronic functional modules for smart clothing applications are positioning, communication and sensor systems, and different types of UI components, for example.

When constructing smart clothes, several functional modules are distributed to optimal locations on clothing according to application design and user comfort. Therefore, the weight and size of the system are adapted. The system distribution results in data transfer requirements between the different modules. Since clothing has to maintain its profound properties, such as washability and wearing comfort, we have to consider carefully suitable solutions for data transfer.

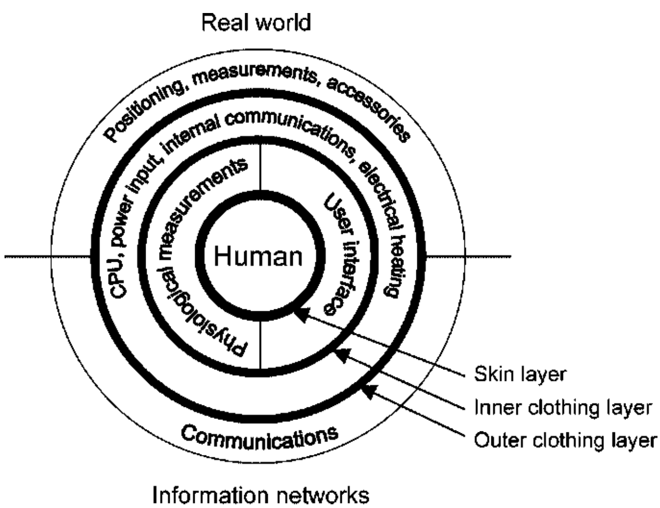
For communication between the different components of smart clothing applications, both wired and wireless technologies are applicable. Wired connections are practical in many cases, but they can cause inflexibility and add to the weight of the system. Wireless connections increase flexibility but also the complexity of a system. Currently, data transfer issues are a true challenge in wearable systems. An applied solution is often a compromise based on application requirements, operational environment, available and known technologies, and costs.

This chapter evaluates the variety of technologies used to realise data transfer in smart clothing applications. Most potential technologies are considered for further analysis. Also, several smart clothing prototypes are introduced, concentrating on their data transfer solutions.

10.2 Smart clothing concept model

In introducing the architecture and functionality of smart clothing and its relation to the environment, a concept model has been used. An individual human user is the centre point of the model that is illustrated in Fig. 10.1. The concept model combines different clothing layers with additional components needed to integrate intelligence into clothing. The main layers concerned with smart clothing are the skin layer and two clothing layers.

Physically the closest clothing layer for a human user is an underwear layer, which transports perspiration away from the skin area. The function of this layer is to keep the interface between a user and the clothes comfortable and thus improve the overall wearing comfort. The second closest layer is an intermediate clothing layer, which consists of the clothes that are between the underclothes and outdoor



10.1 Concept model for smart clothing.

clothing. The main purpose of this layer is considered to be an insulation layer for warming up the body. The outermost layer is an outerwear layer, which protects a human against hard weather conditions.

Additional equipment that is needed to construct smart clothing systems can also be divided into layers in a similar manner. In our division, the underwear layer with additional components corresponds to the skin layer of smart clothing systems. In the same way, the intermediate clothing layer is associated with an inner clothing layer and the outermost layer with an outer clothing layer.

10.2.1 Smart clothing layers

The skin layer is located in close proximity to the skin. In this layer we place components that need direct contact with skin or need to be very close to the skin. Therefore, the layer consists of different UI devices and physiological measurement sensors. The number of the additional components in underwear is limited owing to the light structure of the clothing.

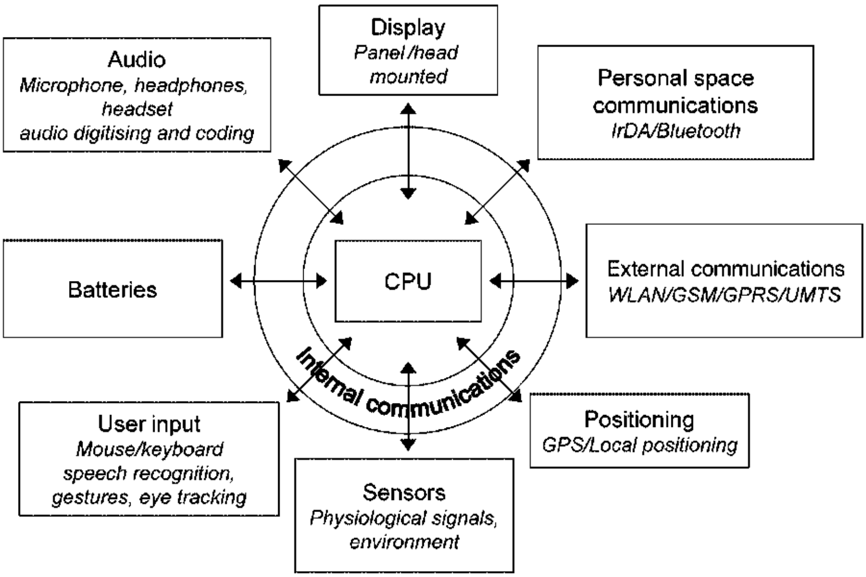
An inner clothing layer contains intermediate clothing equipped with electronic devices that do not need direct contact with skin and, on the other hand, do not need to be close to the surrounding environment. These components may also be larger in size and heavier in weight compared to components associated with underclothes. It is often beneficial to fasten components to the inner clothing layer, as they can be easily hidden. Surrounding clothes also protect electronic modules against cold, dirt and hard knocks.

Generally, the majority of electronic components can be placed on the inner clothing layer. These components include various sensors, a central processing unit (CPU) and communication equipment. Analogous to ordinary clothing, additional heating to warming up a person in cold weather conditions is also associated with this layer. Thus, the inner layer is the most suitable for batteries and power regulating equipment, which are also sources of heat.

The outer clothing layer contains sensors needed for environment measurements, positioning equipment that may need information from the surrounding environment and numerous other accessories. In Fig. 10.1, there are two different worlds (environments) presented that are in contact with the smart clothing. The term real world depicts the physical surroundings of smart clothing components that measure the environment. The term information networks represents the virtual environment accessed by communication technologies. The information networks can consist of communication with the external information systems, such as other network users and database servers.

10.2.2 Smart clothing implementation model

Generally, smart clothes are intended for very specific applications. Therefore, the intelligence is usually implemented using only a few selected components. For



10.2 Block diagram of smart clothing components.

reference, a generic implementation architecture for smart clothing systems is depicted in Fig. 10.2, showing a number of different types of component. The necessary components are CPUs, various UI devices, power management equipment and data transfer components. The rest of the components vary according to the application requirements of the smart clothing system.

Central processing unit

The heart and brain of the smart clothing system is the CPU, where capacity varies according to the computing task. Often in smart clothing applications, small 8 to 16-bit microcontrollers are used.[3,4] In comparison, wearable computing applications usually utilise more powerful processors with speeds of up to 1 GHz.[5–7] The CPU module itself may be a combination of several microcontroller units that are distributed at several locations in the clothing.

User interfaces

UIs in smart clothing consist of several types of input and output devices for information feeding and selection. It is clear that devices suitable for desktop computing cannot be used with smart clothing applications. The ordinary keyboard and mouse have to be replaced by more suitable devices and new input/output concepts must be created. An example of a new innovative input device is the so-called Yo-Yo, which combines a display with a feeding and selecting system.[3]

Alternative input methods are pen-based inputs, gestures, eye movements and speech recognition inputs. The last is a very promising method since it allows hands free operation. Output devices consist of components that give feedback from the function of the clothing or from external actions. These include, for example, displays, loudspeakers, lights and haptic feedback devices. Commonly displays are small liquid crystal displays embedded in a suitable place in the clothing. Obtrusive head mounted displays are suitable for special applications such as protective clothing incorporating a helmet.

Power management

The most important design rule for power management in smart clothing is to minimise the power consumption. Batteries are heavy and thus difficult to place inside smart clothes. A centralised power source is easier for recharging purposes, but leads to wiring requirements for power transfer. A currently available solution is to use Li–polymer batteries that are thin and have a good power capacity. Alternative methods are also used such as kinetic energy and piezoelectric materials.[8,9]

10.3 Data transfer in smart clothing

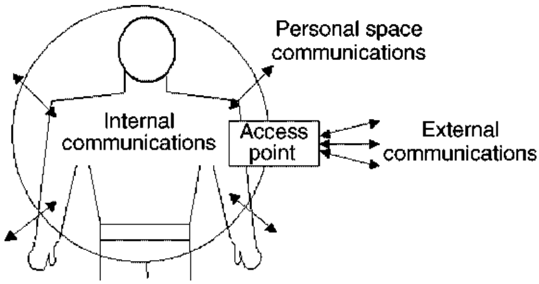
A number of different wired and wireless data transfer technologies are applicable for the requirements placed by smart clothing. The communication model for data transfer in smart clothing and the potential technologies are discussed in the following sections.

10.3.1 Communication layers

Communications in smart clothing are divided into three different data transfer types. The communication model for smart clothing applications is illustrated in Fig. 10.3. First, the internal communication refers to the data transfer between the separate components of a distributed smart clothing implementation. This includes, for example, the data collected from physiological sensors and input/output messages through the UI. As the name implies this communication occurs inside clothes and between different smart clothing layers.

Second, external communication is needed for the data transfer between smart clothes and the external information networks. In a general communication model, there is only one access point at a time enabling the communication. For example, this access point can be a network interface for a cellular data network. The external communication is more easily manageable owing to this single access point.

The third type of communication is called personal space communication. Personal space data exchange takes place in situations when internal communication



10.3 Relations between internal, external and personal space communications.

components initiate data transfer with an environment without a centralised access point, i.e. in an *ad hoc* manner. Personal space is the close proximity of the user, surrounding the human user while stationary or in motion. An example of such technology is a low range wireless link that can be utilised for both internal and external data transfer. The management of *ad hoc* external communications, consisting of possible several parallel dynamic connections, is a challenge for the system design.

10.3.2 Data transfer requirements

The communication requirements for smart clothing are firmly application dependent. A summary of different potential smart clothing applications and services with estimated data transfer requirements is presented in Table 10.1. The estimates presented for possible applications are related to the experience of wearable computer applications.

The transfer requirements can be divided into internal and external. In addition and within the personal space coverage, the external data transfer can be implemented using internal technologies. The internal transfer services are divided into local health and security related measurements, different services provided through a display and audio input/output UIs, and control type of input interfaces. Many of the services require or result in external communications between the smart clothing and its environment. For example, external transfer requirements are placed by the reception of a video or audio stream and text messages.

10.3.3 Wired solutions for internal data transfer

Wired data transfer is in many cases a practical and straightforward solution. Thin wires routed through fabric are an inexpensive and high capacity medium for information and power transfer. However, the detaching and reconnecting of wires decrease user comfort and the usability of clothes. An advanced wired solution is to use conductive fibres to replace ordinary plastic shielded wires. This makes smart clothing more like ordinary clothing. Also lightweight optical fibres are used

Table 10.1 Communication requirements estimates for smart clothing applications

Services/ applications	Data components	Transfer requirements	Technologies
Internal			
Health and security	Physiological measurements	1–20 bit/s 10 s delay bound	Inductive coupling between separate clothing layers, conductive fibres within one clothing layer
UI voice (telephone)	Two-way audio stream	16–64 kbit/s 0.2 s delay bound	Wired and wireless headsets
UI video conferencing	One/two-way compressed low bit rate video Two-way audio stream	128–512 kbit/s 0.2 s delay bound	Cable or wireless link
UI audio streaming	One-way high quality audio	128–256 kbit/s 0.5 s delay bound	Cable or wireless link
UI video streaming	One-way high quality video	512 kbit/s–20 Mbit/s 1 s delay bound	Cable or high-speed wireless link
UI control (input)	One-way control messages (two-way with feed-back devices)	0.1 kbit/s 0.1s delay bound	Cable or wireless link
External			
Web browsing	Web objects: 0.1–10 kB	256 kbit/s 0.5 s delay bound	Wireless high-speed networks
Email	1–5 kB (text only)	9.6 kbit/s 1 min delay bound	Wireless cellular telephone data Wireless high-speed networks
File transfer	1–10 MB files	1–10 Mbit/s 1 min delay bound	Infrared, wired high-speed networks, wireless high-speed networks
Real time media streaming	Two-way audio/ video stream	62–20 Mbit/s 0.2–2 s delay bound	Real-time video and audio streaming
Network games	Two-way control messages 500 B	100 kbit/s 0.50 ms	Wireless high speed
Chat	100–200 character messages	1 kbit/s 2 s delay bound	Cellular telephone short message service
Positioning	Continuous measuring of radio signals	N/A	GPS receiver, local area radio positioning

in wearable applications, but their function has been closer to a sensor than a communication medium.[10,11] Optical fibres are commonly used for health monitoring applications and also for lighting purposes, e.g. in shoes.[12]

Cables

Wired communication implemented by plastic shielded cables is an inexpensive, high capacity and reliable data transfer method. Thin cables can be integrated or embedded inside clothing without affecting its appearance. However, wires form inflexible parts of clothing, thus decreasing the wearing comfort.[3] The cold winter environment especially stiffens the plastic shielding of cables. In hard usage and in cold weather conditions, cracking of wires also becomes a problem.[3]

The connections between the electrical components placed on different pieces of clothing are another challenge when using wires. During dressing and undressing, connectors should be attached or detached, decreasing the usability of clothing. Connectors should be easily fastened (or automatically fastened without special user attention), resulting in the need for new connector technologies.

Electrically conductive fibres

A potential alternative to plastic cables is to replace them with electrically conductive fibres. Conductive yarns twisted from fibres form a soft cable that naturally integrates in the clothing's structure keeping the system as clothing-like as possible. Fibre yarns provide durable, flexible and washable solutions. Electrically conductive yarns are either pure metal yarns or composites of metals with other materials. In composites other materials may, for example, provide strength or weight savings compared to pure metals. Metal clad aramid fibres are an example of strength solutions, which provide good electrical conductivity owing to a copper, silver or nickel coating.[13] A sophisticated solution would be to knit electrically conductive fibre yarns directly into cloths to form natural communication channels. In this way it is possible to construct wearable platforms, which already contain internal communication; only application-specific electrical components need to be added. However, conductive yarns are often used in the same way as plastic shielded cables.

Although this sounds easy, there are a few problems that slow down the usage of conductive fibres in clothing. The first problem is due to the lack of natural insulation material in conductive fibre yarns. Unshielded yarns can also conduct from their surface and this can cause unwanted short circuits when separate yarns are in touch with each other. Also conductive fibre yarns in close proximity, exposed to sweating or to other conductive material between the yarns may cause unwanted electrical conduction.

A possible solution is to embed conductive yarns inside waterproof tape. Tape shielding protects fibres against interferences from the outside world and acts as an

Table 10.2 Fibre yarn connection methods

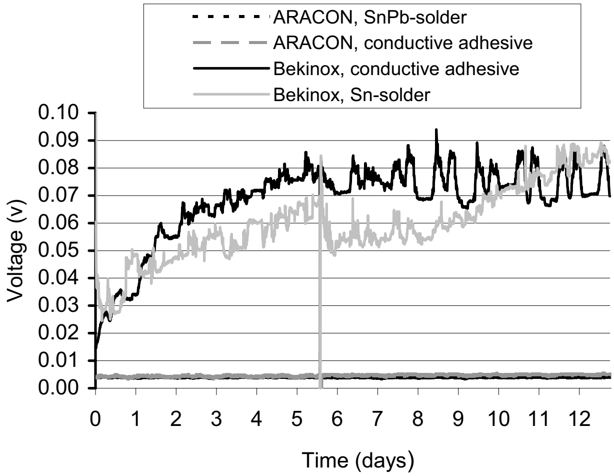
Test fibre yarn	Connection type	Connection material
Bare Aracon®	Surface mount	Tin–lead solder
Shielded Aracon®	Surface mount	Tin–lead solder
Shielded Aracon®	Leading-through	Tin–lead solder
Shielded Aracon®	Leading-through	Conductive adhesive
Shielded Aracon®	Leading-through	Conductive adhesive, silicon elastomer
Bekinox	Leading-through	Tin–lead solder
Bekinox	Leading-through	Conductive adhesive, silicon elastomer

insulator. An example of this kind of shielding is Gore-Seam®, which is used to patch the holes made by the sewing machine and to ensure impermeability.[14] However, this adds working phases during production. Some conductive fibre yarns are also protected by a plastic shell. This kind of protection makes the yarn more like ordinary cable and lessens the clothing-like properties.

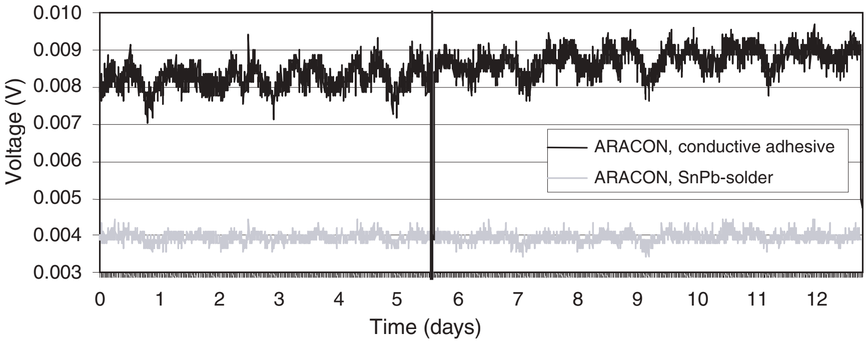
The second problem is due to the reliable connections of conductive fibre yarns. Ordinary cables can be soldered directly to printed circuit boards, but the structure of the fibre yarn is more sensitive to breakage near the solder connections. Protection materials that prevent the movement of the fibre yarn at the interface of the hard solder and the soft yarn must be used. For this purpose, as an example, silicone elastomer intended for electronics can be applied.

Some preliminary tests for connections on conductive fibre yarns and printed wiring boards were made in a laboratory climate chamber in varying humidity and temperature conditions. The materials used were bare metal clad aramid fibres, shielded metal clad aramid fibres, and conductive fibres made from stainless steel.[13,15] The fibre yarns were fastened to test printed circuit boards using tin–lead solder or conductive adhesive.

A summary of the tested connection methods is illustrated in Table 10.2. The test profile was in accordance with the MIL-STD-202F standard. MIL-STD-202 standard establishes uniform methods for testing electronic and electrical component parts, including basic environmental tests to determine resistance to deleterious effects of natural elements and conditions surrounding military operations, and physical and electrical tests (http://www.dscc.dla.mil/Programs/MilSpec/ListDocs.asp?BasicDoc=MIL-STD-202 provides military standards for download). A failure in connection causes the voltage over the connection to become temperature dependent. Therefore, during the test, voltages over the test connections were measured. After these tests, all the connections were functional. In a further analysis we took both stainless steel yarns and the best soldered and adhesive joints made from aramid fibres. In Fig. 10.4 we can see that aramid fibres managed the test better than stainless steel fibres. The graphs of shielded aramid fibre yarns with adhesive joints, silicon elastomer and soldered leading-through joints follow



10.4 Humidity/temperature cycling test performance of stainless steel fibres and metal clad aramid fibres.



10.5 Humidity/temperature cycling test performance of metal clad aramid fibres with adhesive and solder joints.

almost the same path and the fluctuations of their contact voltages are smaller than the fluctuations of stainless steel yarns. These aramid fibre yarn joints are more accurately illustrated in Fig. 10.5. Connections made by Aracon® and tin–lead solder proved to be better than other connections. Joints made by conductive adhesive were worse than solder joints. Generally, shielded fibres endured much better mechanical stress than bare fibres.

10.3.4 Wireless technologies for data transfer

For wireless communications, dedicated external technologies for a wide range and internal technologies within personal space can both be utilised. These are discussed in the following section and summarised in Table 10.3.

Table 10.3 Wireless technologies for internal and external data transfer

Communications technology	Capacity	Service capability	Communication for smart clothing
GSM	43–171 kbit/s	Data and low quality voice	External
SMS/GSM	160 characters of text per message	Text, control messages	External
UMTS	144 kbit/–2 Mbit/s	High speed data, voice	External
IEEE and ETSI WLANs	11–54 Mbit/s	Data, QoS integration for real-time services is emerging	External
Bluetooth	1 Mbit/s	Data and low quality voice	Personal space
IEEE 802.15.1	Same as Bluetooth		
IEEE 802.15.3	55–100 Mbit/s	Emerging for multi-media services	Personal space
IEEE 802.15.4	20–250 kbit/s	Low rate data, control and diagnostics services, user interfaces	Internal
Low power RF	1–100 kbit/s	Control and sensors systems	Internal
Infrared	4 Mbit/s	High speed file transfers	Personal space

External data transfer

Digital cellular data networks, such as global system for mobile telecommunications (GSM), are a current technology for wide area voice and data services for smart clothing applications. GSM represents the latest technological state of current second-generation mobile networks. The system has been developed mainly for voice services, but it also possesses capabilities for general data transfer. Future extensions, such as universal mobile telecommunications systems (UMTS), should bring more bandwidth and enable new, more demanding applications in mobile wide area data networks.[16,17]

A basic service integrated into GSM is short message service (SMS). SMS enables text messages up to 160 characters to be sent between GSM terminals, and several messages can be concatenated. SMS has been found to be a suitable service for the data transfer requirements of varying control applications.

The third generation partnership project (3GPP) is continuing the effort started in the European Telecommunications Standards Institute (ETSI) to develop GSM with higher bit rates and new services. The first changes included an enhanced data rate of 14.4 kbit/s compared to the basic 9.6 kbit/s, still using a single voice call channel. High speed circuit switched data (HSCSD) and general packet radio system (GPRS) belong to the GSM 2.5 generation. HSCSD is an enhancement to the current circuit switched GSM data enabling the reservation of multiple voice channels for a single data transfer connection. With the maximum of four time slots, the symmetric data transfer rate is 57.6 kbit/s. Thus, data rates increase to the level of fixed telephone networks like the B-channel of ISDN (integrated services digital network). The first user terminals available on the market reach 43.2 kbit/s asymmetric data rates.

GPRS brings the GSM system closer to legacy data networks by providing packet access for a GSM terminal and packet switching based routing in the GSM infrastructure. The achieved data transfer rate depends on the availability of GSM channels in use per cell, giving a maximum rate of 171.2 kbit/s. The uplink and downlink data rates are asymmetric. GPRS allows a user to maintain a continuous virtual connection to the network, which facilitates several types of variable data rate services, including internet protocol (IP) based applications.

The work on a new modulation scheme and protocols for the GSM radio interface, called enhanced data rates for GSM evolution (EDGE), should extend the GSM data rates up to 348 kbit/s for HSCSD and GPRS data services, extending the GSM bit rates close to that of the 3G systems.

The terrestrial 3G UMTS will provide at least 144 kbit/s for full mobility applications in all environments, up to 348 kbit/s for macro cell and micro cell environments, and up to 2 Mbit/s short range coverage in micro and pico cell environments with limited mobility.

Wireless local area networks

Wireless local area networks (WLAN) can be utilised for high capacity communications within limited geographical areas, such as homes, offices and public hot-spot areas. Smart clothing applications are generally not expected to demand an office type of data communications, while WLAN is projected for a supplementary technology delivering third generation telecommunication services. Where WLAN infrastructure is available, WLAN provides reliable and low-cost data transfer, meeting most of the projected communication requirements for the external communications of smart clothing applications. Also, the miniaturisation of WLAN technology has proceeded, as WLANs have already been integrated into palm top computers.

The Institute of Electrical and Electronics Engineers (IEEE) standard 802.11 is currently the most widely used WLAN technology.[18,19] The system supports both direct *ad hoc* networking between users and infrastructure-based topology where WLAN access points manage the data transfer between terminals and provide a connection to fixed networks. One of the original 802.11 physical layers uses infrared technology while two of them are spread spectrum radios of the 2.4 GHz industrial, scientific, medical (ISM) band. All original physical layers provide up to 2 Mbit/s link rate.

The further development of IEEE 802.11 has proceeded with new physical layer technologies. The target has been to adapt the WLAN data rates to meet the wired LAN capacity better. Similarly, higher performance *ad hoc* networking has been approached. The 802.11b physical layer standard updates the link rate to 11 Mbit/s. The 802.11b is currently the most utilised physical layer of the existing 802.11 technologies.[20] The IEEE 802.11a standard specifies a physical layer for the 5 GHz band. The maximum link rate achieved with the 802.11a standard is 54 Mbit/s. Furthermore, the emerging 802.11g standard is specifying a 2.4 GHz band radio that has an equal capacity of 54 Mbit/s.

The support of WLAN data transfer quality of service (QoS) is being approached in terms of throughput with the development of higher rate radio layers. The QoS support for IEEE 802.11 WLANs is also being developed in the task group for the 802.11e standard. The purpose is to define procedures to support LAN applications with specific QoS requirements. Transport services for audio, voice and video applications have been appointed in the design requirements.

The European Telecommunications Standards Institute (ETSI) is developing WLAN technology specifications in the broadband radio access networks (BRAN) project. There are also specifications for interfacing existing wired networks.[21] ETSI high performance radio local area network (HIPERLAN) type-1 (HIPERLAN/1) specifies a 5 GHz band radio, with the maximum signalling rate of 23.5 Mbit/s for data transmission. HIPERLAN/1 has a fully distributed network topology. In addition, to extend the network coverage, HIPERLAN/1 utilises multi-hop relaying, in which intermediate terminals can forward received frames towards their final destination. Interconnection with a peer LAN is enabled with a bridging terminal.[22]

HIPERLAN type 2 (HIPERLAN/2) is a mobile short-range access technology for broadband networks, such as IP (over wired LANs). HIPERLAN/2 has a centralised network topology and mobile terminals communicate through an access point in a connection-oriented manner. A capability for *ad hoc* type direct communication between terminals is provided, but a central controller entity is still required to control the data transfer.

The HIPERLAN/2 physical layer technology is similar to the IEEE 802.11a, and the achieved link rate is similarly also 54 Mbit/s. Convergence layers adapt the core network technologies to the HIPERLAN/2. For each of the supported core networks, such as IEEE 802.3 (Ethernet), UMTS and IEEE 1394, a separate convergence layer is specified.

10.3.5 Internal and personal space data transfer

Potential operational frequencies for internal and personal space wireless data transfer are radio bands that do not require a specific licence, special permission or carry licence fees, such as the 2.4 GHz ISM band. In Europe, ISM bands are part of the frequencies allocated for short range devices (SRD). Table 10.4 summarises

Table 10.4 Potential WLAN frequency bands in Europe

Frequency band	Frequencies	Maximum power (EIRP)	Existing/expected technologies and applications
433 MHz ISM	433.05–434.79 MHz	1 mW	RFID technologies, baby monitors, cordless headphones, walkie-talkie phones
868 MHz SRD	868–870 MHz (with several sub band divisions)	5–500 mW	Cordless audio devices, radio microphones, general purpose telemetry, general purpose alarms
2.4 GHz ISM	2.4000–2.4835 GHz	100 mW	WLANs, WPANs
5 GHz HIPERLAN	5.150–5.350 GHz	200 mW	WLAN (indoor only)
	5.470–5.725 GHz	1W	WLAN
5 GHz ISM	5.725–5.875 MHz	25 mW	WLAN, WPAN
17 GHz HIPERLAN	17.1–17.3 GHz	100 mW	WPAN
60 GHz and higher ISM bands	61–61.5 GHz 122–123 GHz 244–246 GHz	N/A	Future development

EIRP = effective isotropic radiated power.

the available ISM bands in Europe, with different existing and emerging technologies and applications.

Potential wireless solutions for internal communications are inductive coupling, infrared and radio frequency (RF) technologies. Low-power RF is more flexible, but these technologies are generally proprietary, while interoperable solutions are emerging for the 2.4 GHz industrial ISM band. However, the standardisation for simpler wireless technologies, targeting at sensor applications is advancing.

Generally, wireless personal area network (WPAN) technology can form a multipurpose link for extending and delivering services to smart clothing applications. WPAN differs from WLAN mainly by non-functional requirements, such as cost and power consumption that favour smart clothing types of applications. Also, WPAN has a smaller operational area, lower data rate and fewer terminals per network compared to WLAN.

Bluetooth is the first available WPAN technology. The technology is a potential standard for low-range RF links, supporting both data and voice services. Bluetooth is a WPAN technology specified by an industry driven organisation called the Bluetooth Special Interest Group (SIG).[23] The main target of the technology is to replace a common serial cable with a wireless link. The non-functional requirements have been emphasised. Thus, the technology targets low cost, low power consumption and small size. Consequently, Bluetooth is expected to be integrated into numerous personal devices, such as palm top computers and mobile phones.

Home and industrial automation has also been a potential application type for such technology.

The Bluetooth radio operates on the same 2.4 GHZ ISM band as current WLANs. The achieved link rate is 1 Mbit/s. The achieved data rate is dependent on the utilised link and packet types. Two link types categorise Bluetooth services. The Asynchronous Connectionless (ACL) data link provides up to 721 kbit/s asymmetric data rate. The Synchronous Connection Oriented (SCO) voice link has a 64 kbit/s rate, and up to three voice connections can exist at the same time.[24]

A Bluetooth link has a centralised access control, but the network (piconet) is constructed automatically in an *ad hoc* fashion between a master node and up to seven slave nodes. In addition, a number of other slaves can be associated with the same piconet while being in a power save mode. Several piconets can form a scatternet, as a Bluetooth node can participate in several piconets at the same time.

The IEEE 802.15 working group standardises WPANs and short distance wireless data communications in general.[25] There are four task groups. Task group 2 is developing practices and mechanisms to facilitate the coexistence of 802.11 WLAN and 802.15 WPAN that operate on the same band. The other groups are developing WPAN technologies.

The first task group of 802.15 (802.15.1) has adopted a WPAN standard from the Bluetooth specification. The 802.15 task group 3 is developing a new standard for a high rate WPAN technology. The target rate has been over 20 Mbit/s, which enables a wider range of personal area applications, such as image and multimedia transfer for consumer electronics appliances. The draft standard defines a physical layer with up to 55 Mbit/s link speed for the 2.4 GHz radio band and a link protocol destined to support multimedia applications. Furthermore, study group 802.15.3a has been recently established to specify an alternative higher rate physical layer targeting an over 100 Mbit/s link rate.

The IEEE 802.15 working group 4 is developing specifications for low data rate WPANs. Target applications are low complexity embedded systems that require a long battery life, such as sensors, interactive toys, remote controls and home automation devices. The draft 802.15.4 standard proposes a single physical layer, but the layer can operate on two different frequency bands. Furthermore, the lower band is either the 868 MHz SRD band in Europe or the 902 MHz ISM band in USA. The higher band is the 2.4 GHz ISM. The targeted link rate is 20 kbit/s for the lower two bands and 250 kbit/s for the 2.4 GHz band.

Infrared communication is widely integrated, for example, in remote controllers, mobile phones, notebooks and digital cameras. Infrared is a low-cost solution but the line-of-sight requirement is problematic especially in devices carried on the body. However, for personal space communication a short-range infrared data transfer can turn out to be a practical and inexpensive solution. Infrared data association (IrDA) has standardised infrared communication with IrDA DATA and IrDA control standards.[26] IrDA DATA defines data transfer for a universal data port, while IrDA control defines data transfer for simple controlling devices such as keyboards and mice. IrDA communication is intended to replace point-to-point cable and it supports data rates up to 4 Mbit/s.

An alternative to infrared communication is low-range and low-power RF communication, which provides more freedom and flexibility to users, since no line-of-sight is needed. The 433.92 MHz and 868 MHz ISM bands are currently used by similar systems, for example in home and office automation applications. As Bluetooth has not emerged as quickly as expected, these low-power RF modules are capturing markets. On the other hand Bluetooth may also turn out to be an expensive and complex solution for the most simple sensor applications.

A recent standardisation approach in IEEE for low power RF systems has been taken in the P1451.5 working group for wireless sensor standards.[27] The purpose for the group is to develop an open standard for wireless transducer communication that can accommodate various existing wireless technologies. The emerging work of the IEEE P1451.5 working groups seems to be very promising for the smart clothing data transfer requirements.

Several RF components suppliers are providing modules with programmable transmission power and with several frequency alternatives. RF link implementations tested at Tampere University of Technology in the Institute of Electronics include ChipCon's circuits CC1000 and CC900, and Nordic VLSI's nRF401circuits.[28–30] The purpose of the study was to find suitable RF link solutions for smart clothing applications. The most important selection criteria were low power consumption and reliable data transfer. In the study, the range, transmission power and the power consumption of the RF circuits were measured. Based on these measurements power consumption per metre was calculated. In these tests CC1000 fulfilled the set requirements best. In addition CC1000 was easy to use and only a few additional components were needed for implementation.

Radio frequency identification technology (RFID) is used in various tracking and identification applications, including smart cards, access control, logistics, sport events, electronic article surveillance and animal identification. A large number of these RFID systems work using an inductive coupling principle in the data transmission.[31] This means the transfer of energy from one circuit to another by means of mutual inductance between these circuits. Another data transfer method is based on propagating electromagnetic waves. These systems provide higher data transfer rates and reading ranges than inductive coupled systems. The main components of the RFID systems are a reader and a tag. In passive systems the reader provides the necessary energy for the operation of the tag, whereas in active systems a separate power source for the tag is needed.

Different transmissions frequencies are classified into three classes; low frequency between 30 and 300 kHz, high frequency from 3 to 30 MHz and ultra high frequency from 300 MHz to 3 GHz and the microwave range above this.[31] These systems can be divided further according to the operation range. In close coupling systems the reader and the tag must be integrated or placed one upon the other and the operation range is up to 1 cm. Remote coupling and long-range systems can operate in the range up to 1 and 10 m, respectively. Generally, higher frequency systems can operate in longer reading ranges.

RFID systems provide low-cost, non line-of-sight wireless links, which makes this technology an attractive alternative to smart clothing applications. For internal communication, low frequency and close coupling RFID systems can be a potential solution for data transfer between different pieces of clothing.

For RFID, communication is generally restricted to the surfaces of clothes, since the strength of the magnetic field decays according to the increasing perpendicular distance from the centre of the reader's loop antenna.[32] This is suitable for smart clothing applications, but in general it is a factor that limits the reading range of RFID systems. Data transfer occurs in small overlapping areas of the reader and the tag. In these systems, inductive coupling works as a connector between different layers of clothing. Remote coupling and long-range systems can be used in certain control types of applications for personal space and external communication purposes.

Usually inductive coupled systems work as single coil systems. However, an example of a new network solution is being developed at Starlab.[33] This fabric area network (FAN) is the first reported inductive coupled communication medium for smart clothing applications. It uses 125 kHz RFID technology and data transfer is limited to a distance smaller than 2 cm. Nodes are routed from a central controlling base station to several locations on the clothing. These nodes can then communicate with tags that come near them.

In addition to inductive coupling, capacitive coupling can also be used in close coupling applications. Capacitive coupling takes place between two coupling surfaces, which are located within a short distance of each other. This coupling method is used in close coupling smart card applications.[31] An interesting approach to capacitive coupling has also been introduced by Zimmerman.[34] In this implementation of PAN, small currents are induced through the human body. The system contains a transmitter and a receiver with a pair of electrodes. The transmitter capacitively couples a small current through the body to the receiver. The return path is the earth (ground) and therefore the body needs to be electrically isolated. Watches, name badges and pocket inserts are examples of devices that can use capacitive PAN technology for data transfer.

10.4 Implementations for communication

In this section, implementations of a wearable computer vest and three smart clothing prototypes are introduced. The emphasis is on the data transfer solutions.

10.4.1 Wearable computer vest

A wearable computer vest, constructed from commercial components in 1998, is illustrated in Fig. 10.6. This wearable computer solution was our first prototype at

10.6 First wearable computer assembly at Tampere University of Technology.

Tampere University of Technology and later solutions have been partly based on the experiences acquired. The platform for the computer system is the vest, which contains several pockets for additional components. The function of the application is to be a general helper, providing a variety of data processing functions in everyday situations. The computer is as mobile as its user. The CPU in this solution is Via II, which is integrated into the back of the vest.[5]

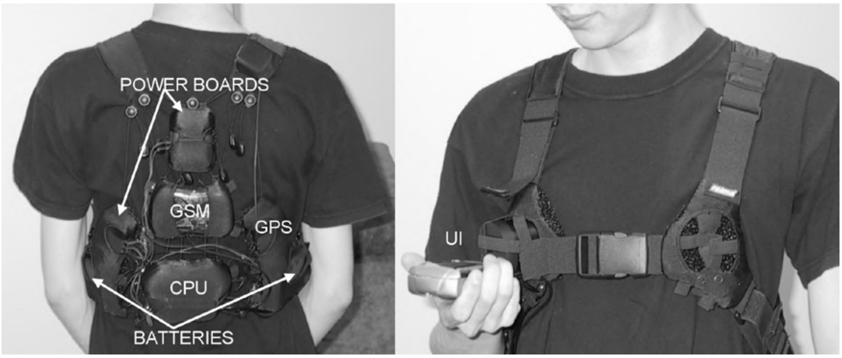
A head mounted display V-Cap 1000 manufactured by Virtual Vision Inc. is connected to the CPU module with a thick and inflexible cable. The cable is a bit clumsy, although now there are also wireless solutions available on the markets. The input device in the configuration presented in Fig. 10.6 is a chording keyboard called Twiddler, which allows one hand operation.[35] In the vest, the connector cable for Twiddler is a problem and a wireless solution would be better. The application has also two different positioning systems. First, we use an infrared-based tag system indoors.[36] Second, we can use global positioning system (GPS) outdoors. Continuous connection to the internet and other information networks is

10.7 Reima smart clothing prototype for the arctic environment.

achieved using a WLAN (Lucent WaveLAN) network adapter within the premises of the Institute of Electronics. In other places we can use a GSM card phone (Nokia).[37]

10.4.2 Reima survival suit

A Reima smart clothing prototype illustrated in Fig. 10.7 is intended to assist survival in the arctic environment. The prototype is suitable for several activities in a harsh winter environment, but the special target user group is experienced



10.8 Support structure for Reima smart clothing prototype.

snowmobile users. The prototype suit consists of underclothes, a supporting vest and an actual snowmobile jacket and trousers.

The function of the prototype is to prevent accidents and, on the other hand, help users to survive longer in the case where an accident has already happened. The suit is capable of acquiring information of the wearer's health, location and movements. With several types of integrated sensors, it is possible to monitor the user's condition and position. If a user encounters an accident or another abnormal situation, the suit will inform an emergency office or use another preselected phone number via the SMS of the GSM modem. The user can also send an emergency message him- or herself. The message contains the current coordinates of the user's position, the data from the user and the environment measurements. The coordinates are acquired using GPS.

The three-layer structure of the suit allows data transfer between different pieces of clothing. Special underwear (i.e. the skin layer) incorporate a heart rate sensor and electrical heating panels in the end of the sleeves. In this prototype, a special supporting structure forming an inner clothing layer is embedded inside the snowmobile jacket. This supporting vest illustrated in Fig. 10.8 contains most of the electrical components.

The outerwear contains a few environment measurement sensors and UI devices. The UI consists of three separate devices: a small loudspeaker on the collar of the outerwear, a light feedback device in the sleeve of the jacket and the Yo-Yo interface in the front pocket of the jacket. The UI is physically placed on the outerwear since we have to operate with it continuously in the cold winter environment.

Cables were used for internal data transfer between the CPU and other components. Selection between different types of cables was done so that the plastic shielding would also endure in harsh environments. Since cables were used in data transfer between different pieces of clothing, some extra connectors were needed. However, this was the only possible solution, since the heavy batteries needed for heating were not practical in the structure of the underwear. Cables

10.9 Sensor shirt and heating jacket.

were also used for data transfer between the CPU and the Yo-Yo. In contrast, wireless data transfer is used between the heart rate sensor and the CPU. This is implemented by using a low frequency magnetic field.

Since the UI is in the breast pocket it is subject to weather effects. Therefore, a wireless link between the UI and the CPU would be more reliable. A number of wires are placed into the supporting vest, but its structure is a natural platform for fastening cables. In addition, it is not possible to replace these cables with fibres, and replacing them with wireless links could cause them to interfere with each other. In this case, wires were the best solution. Further information on the smart clothing prototype can be obtained from Rantanen *et al.*[3]

10.4.3 Heating jacket and sensor shirt

An electrically heated smart clothing prototype is illustrated in Fig. 10.9.[38] On the left is the sensor shirt, which is a platform for sensors and essential measurement electronics. The heating control is based on the physiological measurements made by the shirt. On the right is the actual heating jacket, which contains heating elements, voltage regulation electronics and power control electronics. The main target of the whole system is to help the user to reach a condition of thermal comfort. The sensor shirt is also functional without the heating jacket.

The temperature sensors measure skin surface temperature at ten different

10.10 A PPM vest.

places. In addition, skin conductivity and respiration can be measured. Data transfer between the measurement electronics and the temperature sensors is implemented by electrically conductive fibre yarns. The same yarn is also used for skin conductivity electrodes. The fibre yarn makes the shirt soft and comfortable to wear, but connections between the yarns and the temperature sensors are unreliable. The shielding rubber that covers the connections is too hard for yarns and causes breakage of the structure of yarns. The measurement electronics boards are located so close to each other that cables can be easily used for data transfer between them.

A test UI for the application is a personal digital assistant (PDA), which is connected to the CPU by a serial cable. This cable causes disturbance and should be replaced by a suitable wireless link. Communication inside the jacket is implemented by cables.

10.4.4 Personal position manager

The personal position manager (PPM) uses a fishing vest as a platform for electrical devices. PPM is an application that is particularly intended for outdoor activity, such as fishing and hiking.[39] The basic function of the system is to record good fishing places, so that fishermen can find places for the best catch again. It is also possible to request the route to a desired destination point that was saved earlier into system's memory, to record continuously the last 10 km of route travelled and to follow a route travelled. In this implementation, the requirements of easy usage and low power consumption guided the design process. A PPM is illustrated in Fig. 10.10.

The system consists of a GPS for position tracking, a CPU to control the function of the vest, a power source and two types of UI. PDA with implemented UI is used for navigation and a touch button UI is used for marking interesting places. The majority of the components are hidden between the outerwear cloth and lining of the fishing vest. Only the UIs are placed on the surface side of the vest so that they are accessible all the time. Special pockets for components are sewn inside the vest and therefore cables are the natural solution to connect the distributed components to each other. At the beginning, we also used a cable between CPU and PDA UI. However, it proved difficult to use since the connector easily detached and the extra cable hanging from the pocket was a negative alternative visually. We have now replaced the cable by a low-power RF link. The RF communication is implemented by using ChipCon's CC1000 circuit.[28]

10.5 Summary

A number of wired and wireless data transfer technologies are available for smart clothing applications. For wearability, conductive fibres are seen as the most suitable wired solution, while ordinary cables provide high reliability. Low-power wireless connections provide increased flexibility and also enable external data transfer within the personal space. Different existing and emerging WLAN and WPAN types of technologies are general purpose solutions for the external communications, providing both high speed transfer and low costs. For wider area communications and full mobility, cellular data networks are currently the only practical possibility. Experiences with prototypes have shown the operability and potential of smart clothing, and also indicated the need for research work on new technologies and usability.

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