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1. INTRODUCTION

World market has become very competitive in the business and premiere class segments as this tend to yield higher profit margin in comparison with the economy whose margins have been undercut by the new low-cost airlines. The arrival of the new booming economies of China and India and the existing tiger economies pushed the demand for business travelers on long haul flights very high. The airlines responded by offering new level of comfort and sophistication.

China Southern Airlines, the largest airline in The People's Republic of China, is putting the "Premium" back into its world-famed Premium Business Class with the addition of new cocoon-style shell flat bed seats in its new Airbus A330 aircraft.

Currently under construction in Toulouse, France, the brand-new Airbus A330 aircraft will feature 24 Minipod Premium Business Class seats from B/E Aerospace, Inc. (Nasdaq: BEAV). Minipod has won four prestigious design awards and has been nominated for Flight International's 2004 Aerospace Industry Award.

"Clearly setting the standard in Business Class service in China and throughout Asia, China Southern is putting the emphasis on Premium," said Mr. Li Kun, Vice President, China Southern Airlines. He added that the new minipod design, "offers all of the key design features that our Premium Business Class customer expects of China's largest and best airline."

China Southern Airlines' all-new Premium Business Class seats feature:

- An ergonomically-designed fixed privacy shell which transforms into an eight degree flat bed - 1.9 meters long. The entire seat translates forward - and widens - in one swift motion … offering a private fixed living space for each passenger

- Independent rotating leg rest adjustments which raises up and down - provides support to lower legs and calves

- Electrically extending foot rest extension and bottom cushion extension which lengthens and shortens

- Fully adjustable, automatic lumbar massage function

- Multi-functional telephone and video control unit which controls 10.4 inch LCD tilting viewing screen and on-board music channels

- Easily accessible, AC power plug for laptops, CD and MP3 players – no adaptor needed

- Private storage cavity and hip recess for added personal convenience

- 58 inches of pitch between shell pods

- Individual directional LED reading light with full intermediate dimming

- Pull-out privacy divider separating each passenger

Other airlines from Australia, Malaysia and Indonesia offer

CHOICE OF THREE CABINS:

ECONOMY: Ergonomically designed seats with in-built lumbar support and manually adjustable 'wings' in headrest for extra head and neck support, personal TV screens featuring a wide choice of films, programmes and games.

INTERNATIONAL BUSINESS CLASS: award-winning, forward facing 6'6" Skybed with built in back massager, cocoon-style seat design for extra privacy, flexible in-flight dining options, personal video screen and self-service bar, including drinks and snacks.

FIRST: full length electronic sleeper seat converting to flat bed, duvet, wool blankets and oversize pillow, fine champagne and premium wines, individual touch screens with on-board library featuring premiere, world, classic & family titles.

From the original A300 to the new A380, Airbus jetliners offer the optimum experience for passengers in terms of seating, carry-on baggage stowage and in-flight entertainment.

The A300 and A310 – which were the first Airbus aircraft in airline service – ushered in a new era of airline travel by providing true widebody comfort in the 220-250-seat airliner category. Their 222-inch fuselage cross-section offers the best seating layout in all classes. In first class, the roomy environment accommodates top-of-the-line premium seats, while there never is a middle seat in business class. The comfortable eight-abreast arrangement in economy offers more space than any competing aircraft, with no passenger further than one seat away from an aisle or window.

Passengers also appreciate the A300 and A310 for their quiet cabins. The optimised fuselage cross-section also provides more overhead storage, which is further maximised with the specialised deep bin profile developed by Airbus.

On its higher-capacity, longer-range A330 and A340, Airbus introduced improvements in soundproofing to lower noise levels even further, and incorporated the latest in-flight entertainment and communications systems for passengers. New cabin interiors developed by Airbus feature sleek and harmonious lines and unrivalled spaciousness, all while retaining the optimised 222-inch Airbus widebody cross-section. On the A340-600, which is the largest Airbus in revenue service today, airlines have introduced new features such as lower-deck facilities – including galleys with a trolley lift to main deck – creating more seating capacity on the main deck. In addition, operators are installing mini suites in first class cabins and are using the Airbus In Flight Information System.

Even on ultra long-haul service, widebody Airbus airliners receive top marks from passengers in all classes. This is confirmed by the highly positive feedback from Singapore Airlines customers on non-stop A340-500 service from the carrier's home city to Los Angeles and New York – the longest routes in the world. Singapore Airlines' A340-500 even features mood lighting to create the right environment during various segments of the extended flight.

When Airbus entered the 150-seat airliner market with its A320 Family, the company brought the widest cabin to the single-aisle category – once again setting new standards for passenger comfort and cabin flexibility. Its larger aisles facilitate the boarding/disembarkment process, helping speed up the turnaround time that is essential for low-cost carriers and other airlines. As with Airbus widebody aircraft, the A320 Family's cabin shape allows for larger overhead stowage.

The Airbus tradition in cabin excellence is being applied to the 555-seat A380, with will open a new era in airline travel when it enters service in 2006. The A380 will deliver an unparalleled level of comfort, with wider seats and aisles in all classes of service, open spaces for passengers to stretch their legs and access to lower-deck amenities such as bars and a duty-free sales area. Airlines ordering the A380 are planning innovative uses of the aircraft's three decks, including the use of showers and lounges planned for Emirates' aircraft.

However, all this improvements require the passenger to constantly search for optimal settings and do not allow for important features such as noise and climate regulation, which are crucial elements in the passengers' perception for comfort.

2. CABIN ENVIRONMENT ISSUES AND HUMIDITY CONTROL

With respect to the assignments in SEAT the CTU Prague group has focused its investigation onto relevant research results and publications from the following three areas of science and engineering:

- Cabin environment conditions and their impact on the passenger's well-being
- Analysis and design of airflow in the aircraft cabin
- Humidity control technology in the airplanes

2.1. Cabin environment conditions and their impact on the passenger's well-being

There is an immense amount of papers, reports and other sources dealing with physiological and pathological impacts of pressure changes, reduced oxygen supply, noise, acceleration, temperature variations, low humidity and stress on flight passengers and aircrews. Although the modern commercial airplanes are quiet and comfortable compared with previous generation of aircrafts a significant percentage of air travellers may suffer health problems from the airplane cabin conditions – either during the flight or in the consequence of the air trip. There are still serious cabin environment factors which may cause stress and **harmfully affect health** of vulnerable individuals. A safe, healthful and comfortable environment for passengers and crew is to be provided by the environmental control system (ECS) of the aircraft. As an artificially worked out environment the airline cabin air is characterized by numerous parameters which may affect the passenger's fitness and health. The following cabin environment conditions may become s**tressing factors** during the flight: cabin pressure, cabin air humidity, oxygen saturation, motion and vibration of the aircraft, noise, available space per person and a lack of seating variability. While pressure or oxygen content variations and motion or vibration may result in nausea, other factors affect the passenger's well-being in a **less dramatic way** but just that is why their health impact may be even more serious.

The first part of this section deals with the air ventilation in a regular aircraft and its cabin air quality. In the second part, the issue of humidity of the cabin air are being discussed. The factors affecting the passengers' health are summarized in the section three while a special attention is paid to the effects of low relative humidity in the aircraft in the section four.

2.1.1 Air ventilation system and aircraft cabin air quality

The external environments of the aircraft vary dramatically during the flight, namely the outside temperature from below -55°C to over 50°C, the outdoor pressure from about 10 kPa to 100 kPa, and relative humidity from virtually dry to saturated state. That is why a powerful and reliable environmental control system (ECS) is to be a system capable to provide a favourable indoor environment inside the modern aircraft (ACE 2002). The key functions of the ECS are

- pressurization
- contaminant removal
- air distribution and circulation
- temperature control
- recently also humidity control

The standards for ECS regarding the above mentioned issues are defined by the Federal Aviation Regulations (FAR)[1] (section 25, Airworthiness standards: Transport category airplanes) in the United States, while in the Europe by the Joint Aviation Requirements (JAR)[2] (section 25, Airworthiness standards: Large Airplanes).

2.1.2. Pressurization.

During the flight, the ECS maintains the cabin pressure and therefore oxygen partial pressure PO_2 at acceptable levels. In fact maintaining PO_2 is the primary purpose of the pressurization, i.e. compressing the thin outside air. According to FAR, the minimal cabin pressure is 75 kPa (16 kPa PO_2) which corresponds to the altitude 2440 m above the sea level. Thus the cabin pressure can range from 101 to 75 kPa (21 to 16 kPa PO_2) regardless of the altitude at which the aircraft flies (ACE 2002). The ECS must also prevent rapid cabin pressure changes arising due to either an ascent or descent during the flight.

2.1.3. Contaminant removal.

The main contaminant generated in the cabin is CO_2 while the minor contaminants are CO, particulate matter, volatile organic compounds, etc. Without air exchange, it would take typically less than three minutes for the concentration of CO_2 in cabin air to exceed the recommended upper limit of 1,000 ppm (parts per million), (Hinningofen and Enck, 2006). Particularly due to the CO_2 concentration intensive cabin ventilation with the outside air is inevitable since this concentration increases very quickly. As a standard to provide comfort for most passengers usually the approximate rate of 8 to 10 litres per person and second is considered. This corresponds to the rates of air exchange in the cabin as high as about 20-25 times per hour. However, the reported measurements in cabins with recirculation have shown unambiguously negative impact of this arrangement on the cabin air quality particularly on the concentration of CO_2 (Hocking, 1998). The more the medical aspects are emphasized the higher percentage of fresh air is recommended for cabin ventilation. The measurements have even verified as granted that the standard of 8 to 10 litres per second and person is not sufficient and should be increased on 9 to 12 in order to maintain the CO_2 concentration at least at admissible 760 ppm. New models of aircraft use recirculation to a greater degree than older models in the fleet. Specific concerns regarding the cabin air quality include not only the amount of outside air, but also the adverse effects that might result from the exposure to this confined environment, (Lee et al., 1999). The air that is used for ventilation is the same air that is used for pressurization. Notice that the oxygen consumed by the aircraft occupants has only negligible effect on PO_2 (around 0.8% PO_2 drop) (ACE, 2002). The primary contaminant originating outside the cabin is the ozone O_3, which is taken to the cabin with the outside air at high altitudes. To remove O_3 from the outside air before it is supplied to ECS the ozone converters are used.

2.1.4. Air distribution and circulation.

The ventilation system of ECS does not only supply the outside air to the cabin but it also distributes the cabin air and provides its circulation. The above mentioned demand on supplying 8 to 10 litres of outside air per second for each passenger represents a rather high ventilation performance necessary for maintaining an acceptable level of contaminants. This amount of conveyed air brings about a necessity of considerable streams, i.e. draughts in the cabin air and the motion of the air brings about considerable risks of transferring the contaminants, micro-organisms, airborne bacteria and infection diseases, respiratory tract infections etc. Due to this danger it is required to provide the ventilation flows only in the

[1] FRA (Federal Aviation Regulations), Federal Aviation Administration, www.faa.gov
[2] JAR (Joint Aviation Requirements), Joint Aviation Authorities, www.jaa.nl

directions parallel with the cabin cross-section plane, while any lengthwise air movement is to be prevented from. A higher frequency of upper respiratory tract infections among aircraft passengers was investigated by Hocking and Foster (2004). Typically, air is supplied and exhausted along the whole length of the cabin through the diffusers located in the centre of the ceiling of the aisles, above the windows, or along the overhead baggage compartments. Exhausted air generally is removed from the cabin at floor level and at the side walls. Ideally, the spread of contaminants along the length of the cabin is avoided by balancing inflow and outflow at all locations. Due to substantial energy cost of supplying compressed air to the cabin in flight, some of the exhausted air from the cabin is **recirculated** to the cabin after passing through filters (particle or HEPA filter) which remove the particles and airborne pathogens. The percentage of recirculated air distributed to the cabin typically is 30-55% of the total air supply. However, some of the aircrafts in operation still use 100% outside air supply (ACE, 2002). As a rule, the 100% outside air supply is almost always used for the cockpit ventilation.

The **cabin air recirculation** turned out to be an involved issue. On the one hand it offers significant energy and fuel savings, but on the other hand the aboard measurements have confirmed worsened levels of CO_2 if the recirculation is applied. As to the new airplanes some air recirculation is a prevailing characteristic of ECS, but the rate of recirculation is a parameter the optimum of which is not settled definitely, since it seems to become a matter of trade-off.

2.1.5. Temperature control.

The temperature of the air in the cabin controlled by ECS is done by the combination of the temperature of the air supplied to the cabin and by the flow rate of the conditioned air. The temperature of the air supplied to the cabin is adjusted by mixing the cold air, which is a mixture of the outside air and filtered recirculated air, with the hot outside trim air (pre-processed air taken from the compressor of the engine) before it enters the cabin. To prevent uncomfortable cold drafts near the inlets in the cabin, the minimal temperature of the air supplied to the cabin is 10°C. In some airplanes, additional thermal control is available to each passenger through gaspers. Because of the high occupant density, cooling of the cabin is required most of the time, particularly on the ground and low altitudes in warm climates.

2.1.6. *Humidity of the cabin air*

Relative humidity is not routinely monitored in commercial aircraft, but some measurements have been reported as part of several research investigations involving small numbers of flights. At cruise altitudes the results of those measurements are consistent with expected humidity and indicate the absence of other major sources of moisture during the flight (Lee et al. 2000, Nagda et al. 2001). Inside air humidity is controlled both for the traveller's comfort and aircraft safety. These two needs are sometimes compatible but mostly they stand in conflict. A tendency to higher humidity of the cabin air can appear primarily during taxiing on the airport when the inlet air is to be dehumidified. On the contrary at the cruising altitudes the intensive ventilation provided by the extremely dry outside air leads to rather low humidity of cabin air. A substantial source of moisture is the passengers, i.e. the moisture from their exhaled air and from their skin.

The **conflict** of humidity requirements consists in the fact that while a humidity level from 30 to 40% is satisfactory for the **passengers** a rather dry air is favourable for the **electronic systems**. One has to be aware of the tremendous temperature difference between the outdoor and indoor air. Due to the extremely low outside temperature the **dew point conditions** may appear inside the air-cabin wall even if the humidity in the cabin interior is very modest. A particular threat of massive condensation is in the space over the ceiling of the cabin, the so-

called crown area, where even heavy ice layers may develop. A further contradictory aspect arises in considerable **power demands** for ventilation and conditioning the outside air which force the airline companies to introduce air **recirculation**.

The level of relative humidity in the aircraft cabin is determined by the ECS performance via intensive ventilation by the outside air. The modern airplanes cruise normally at an altitude from 9,000 to 13,000 m where the air is extremely dry and markedly thin. Thus – without humidification – an inevitable consequence of cabin ventilation is a considerable decrease of cabin air humidity. The longer is the flight the deeper is the **humidity dropping**. Due to ventilation the measurements on board have shown surprisingly rapid relative humidity droppings – from at least 47% to 11% already within only 30 min of flight (Eng et al., 1982). During the long flights humidity droppings to 5% RH and even lower have to be considered unavoidable if the humidification is not applied (Haghighat, 1999). It has been shown in measurements done by (BRE, 2004) that the level of RH during the flight depends also on the outside air ventilation mode. If 100% outside air ventilation mode is used, RH droppings are considerable faster than if the ventilation mode with mixed outside and **recirculated** cabin air is used. It is due to air humidity generated by the passengers which is temporarily kept in the cabin air by the recirculation. However, the steady supply of dry outside air by ECS is more than sufficient to flush the human-generated moisture from the cabin and after some time of cruise, the RH drops below the above mentioned 5-10 %. As to the humidity droppings it is necessary to be aware of the fact that they are worse in the business than in the travel class, apparently due to the lower density of passengers.

A natural solution of the low humidity in the cabin is to humidify the cabin air using humidifiers. However, number of problems is associated with the humidification, including weight penalty associated with the water that need to be carried and the biological growth that is often associated with humidifiers. Increasing the level of relative humidity in the cabin can also lead to condensation, dripping and freezing of moisture on the inside of the aircraft shell, which can lead to variety of safety problems. Even though ECS of majority of modern aircrafts **do not use humidifiers** to increase RH during the flight, there exist several companies developing the humidification systems for the aircrafts (the principles of these humidifiers will be described in section 3). Humidification of the cockpit is more frequently used than humidification of the whole cabin, however, due to higher ventilation rate in the cockpit, the air in the cockpit is usually maintained drier in majority of modern aircrafts.

2.1.7. *Factors affecting the passenger health*

In aircraft people are exposed to a particular combination of low relative humidity, reduced air pressure, presence of ozone and other pollutants proved as harmful to human health as well as to cosmic radiation. A number of studies have been devoted to these issues on commercial airlines. Spengler et al. (1994) studied indoor air pollutant levels of carbondioxide (CO_2), carbon monooxide (CO), ozone (O_3), dust, relative humidity (RH) etc. in 22 flights with aircrafts manufactured by McDonnell-Douglas, Boeing and Airbus. Average CO_2 levels during the flight with partially recirculeted air were twice the levels measured on flights with 100% outdoor air system during cruise. Let be remarked that the reported cases of re-circulation considered that each of the passengers was receiving 4 litres per second, i.e. approximately one half of the case of 100% outdoor air supply. The consequence: the levels of CO_2 are then increasing at about 1500 ppm which is controversary to medical recommendations.

Cabin air quality has generated considerable public and worker's concern and controversy in the last few years. To clarify the situation Aerospace Medical Association requested the Passenger Health Subcommittee of the Air Transport Medicine Committee to review the

problems and to prepare a position statement (Thibeault, 1997). Confusing discomfort and health risks were identified in the problem area as well as a lack of clear definitions has been found. The conclusions and recommendations primarily support the smoking free regime in the passenger air transport, an increased moisture intake to overcome the low humidity health impacts, higher efficiency in particulate filtering and more distinguish between the short or medium and long flights.

A thorough review of cabin air humidity problems has been published by Nagda and Hodgson, (2001). Very cautious recommendations concerning the in-flight health emergencies can be found in Kay (1994), where the reports to the Federal Aviation Administration (U.S.A.) are quoted. The incidence of in-flight emergencies is very low, but with regard the **tremendous number of airline passengers** – more than one billion in a year – the number of people which experience serious medical problems is of the range about 30,000. As the main environment factors with a negative health impact the lower partial oxygene pressure (reduction to about 75% as it is given by Federal Aviation Regulation) and humidity droppings are considered. It is necessary to realize that the airplanes today are able to fly non-stop even more than 15 hours and therefore the long flight time changes deeply the significance scale, particularly as regards the otherwise less obvious impacts of indoor environment parameters.

To conclude this section it is to realize that the cabin environment issues are not only issues of passenger's comfort but, first of all, significant problems concerning the **health risks** of air travellers public and aircraft crews. The problems like common cold or influenza-like illness transmission, deep vein thrombosis, dehydration with increased viscosity in the respiratory tract are to be considered as being markedly influenced by cabin indoor environment. Also the impact artificial cabin environment on allergic persons is a matter of high attention and investigation. Education about the potential problems associated with air travel is the primary means of prevention of in-flight emergencies.

2.1.8. *Effects of low relative humidity on passenger health*

According to the Report of BRE (2001), low humidity can have direct effects on passenger's health and comfort and the range of these effects is dependent on the humidity lack, the duration of exposure and other factors (e.g. temperature, water ingestion, wearing contact lenses, use of moisturiser etc.). The main potential problems are:

- drying of the body surface (mucous membranes and skin)
- dehydration
- lower perception of poor air quality at low RH
- effects on thermal comfort (feeling cooler at lower RH, especially at higher temperatures).

As to the dehydration humidity has many indirect effects, relating to several other factors that are addressed in (BRE, 2001):

- Dehydration is a possible factor in Deep Venous Thrombosis (DVT) and jet leg (see also Bagshaw (1996) and Simons and Krol (1996)).
- Low relative humidity (in combination with temperature) affects the generation of body odour and emissions from materials.
- At the cruising altitude humidification may cause condensation on surfaces with associated risks of electronic system failures and microbial growth.
- Humidity affects the viability of some pathogens in the air, some being favoured by low RH and some by high RH.

- The effectiveness of the mucous membranes in defending against infection could also be compromised by low humidity.

The physiological stresses in air travelers connected with low humidity are described in Owe and Christensen (1998), (Lindgren et al. 2000). In Thibeault (1997) it has been cited an Aerospace Medical Association (AsMA) conclusion that the common recommendation of increased fluid intake during air travel is all that is needed to control the mild side effects of low humidity. However, in (Bagshaw 1996) it has been emphasized that there is no evidence that exposure to a low humidity environment can lead to dehydration. This assertion is based on a Royal Air Force study (Stroud et al. 1992) which revealed that "Although low humidity caused mild symptoms such as nasal dryness, subjects' performance and mood the well-being was unaffected", as cited by Thibeault (1997). Later on, this investigation went on that the maximum possible increase in body water loss over an eight-hours period in a zero humidity environment, compared with day-to-day environment, is only around 100mL (for more details see Nicholson 1996).

2.2. Analysis and design of airflow in the aircraft cabin

2.2.1. Environmental control system

The Environmental control system (ECS) in a typical modern aircraft can be briefly described as follows (ACE, 2002). The outside air supplied to the cabin (so-called bleed air) is taken from the **compressors** of propulsion engines. The **bleed air** which is of high temperature and pressure passes through a pre-cooler and its pressure is reduced by a pressure control system. The air then passes through the ozone converter and it is led to the air-conditioning packs where it is further cooled. From the packs air is supplied to the common cabin air distribution system where, in the mixing manifold, it is mixed with the filtered **recirculated air** taken from the cabin. Finally by mixing the air with the trim air, i.e. the air which bypasses the air-conditioning packs, the temperature of the air is controlled and this mixture is supplied to the cabin through the diffusers. Accurate cabin pressure is maintained by one or more outflow valves that automatically regulate the flow of air out of the aircraft pressure hull to the ambient environment. Various sophisticated schemes of compressing, expanding, cooling and mixing the outdoor and recirculated air are used to provide sufficient ventilation and air-conditioning of the aircraft interior.

2.2.2. Computer fluid dynamics

It is apparent from the high demands on fresh air supply and cabin ventilation that a relatively intensive ventilation flows are to be provided in both the cabin and the cockpit. In designing the air-conditioning system accurate predictions of flow patterns in aircraft cabins are of prime importance in the commercial aerospace industry. The comfort of passengers depends on the control of temperature distribution and air quality within the cabin. The design of environmental control system for an airplane interior involves specification of supply and return airflow quantities, air velocities and ventilation duct locations in order to yield an appropriate air distribution performance. Full-size airplane cabin **mock-ups** continue to be used to assist in this process, but the expense and time required for testing, limits the number of airflow systems that can be analyzed. **Computational fluid dynamics** (CFD) techniques facilitate a fast and inexpensive evaluation of design studies. Unlike exterior aerodynamics studies, where the solution of simplified model equations is available, in interior ventilation flows the Navier – Stokes equations are to be applied, due to the viscous and extensively recirculating nature of the flows (Aboosaidi et al., 1992, Horstman, 1988, Kwak et al., 1986). Due to the requirement to achieve the **ventilation flows parallel** with the **cross-section plane** the two-dimensional models seem to be relevant and satisfactory for the ventilation studies.

However, so far the flow models have been developed for the speed-temperature distributions and no similar investigations have been found for humidity distributions so far. Although the available modelling reports are devoted to the temperature fields in the cabin they can be utilized for our intents to model the space **distribution of relative humidity** in case of a convection supply of humidified air. Particularly the "smart seat" solutions will require model studies for designing individual one-seat humidity adjustments. An inspiration can be found in the research work by Penot and Meyer, (2000), where an annular jet is used for local temperature control around a passenger.

2.3. Humidity control technology in the airplanes

2.3.1. Humidifying principles

The problem of too dry cabin air is not new and various humidifying systems have been already designed and produced for the aircraft cabins. So far, three humidification principles have been developed for the airplanes, which are based on humidifying the dry air by:

- atomized water spray
- steam boiler devices
- water surface evaporation

Atomized water spray based humidification. This type of aircraft humidifiers generate **atomized water spray** which is introduced into the flight deck by the air-conditioning ducts. The spray is produced by rotating, vaned disc, which is driven by a motor. Water is drawn, via an aspiration tube, from a chamber at the base of the unit. This technique was featured with the need of a relatively high-power motor to drive the disc. A problematic feature of such humidification is that the humidifier, in the water spray, distributes into air minerals from the potable water supply. This may result in mineral build-up in some sensitive parts of the air ventilation system, e.g. on switch contacts, and consequently it may cause hazardous situation. In the same way as the minerals, also the bacteria from the water supply can be distributed into the ventilation by the ventilation system. Due to these and numerous other problems this principle has been abandoned.

Steam-boiler based humidification. The humidification is based on producing **water vapour** in a boiling unit and on a controlled mixing it with circulating air. The air passes through the integrated humidifiers and is being led out into the cabin by the ventilation system. Compare to the previous humidification principle, the advantage of this approach is that the steam humidified air is free of minerals as well as bacteria originating from the water supply. This principle is used in the "Humispace" cabin humidifier produced by the company Le Bozec Filtration & Systems[3]. The humidifier is reported to be approved and used by the main airplane manufacturers including Airbus and Boeing. A similar approach is also used in the system developed by Liebherr Aerospace[4] company where a heat exchanger is used to generate steam for the humidifier with the help of hot air emitted from the aircraft's engine. The humidifier is reported to be an option for Bombardier Global Express business jet.

Water surface evaporation based humidification. The humidification is based on principle of evaporation from a **free water surface**. The core of the humidifier is a cellular substance pad possessing an enormously large contact surface for air and water. It guarantees a sufficient water mass transfer into the air flow through this moisture transferring cell pad.

[3] Le Bozec Filtration & Systems, www.le-bozec.com
[4] Liebherr Aerosapce, www.liebherr.com/ae/en

Fresh water from the potable water system is distributed over the cell pad through which the air stream passes and is humidified via water surface evaporation principle. This humidification technique is robust and simple, no boilers and aerosols are involved. The principle is used in CAIR system of the company CTT Systems[5] which consists of the Zonal Drying system and a system for humidifying a portions of the aircraft's passengers and crew areas. The core of the humidifier in CAIR system is a GLASdek pad (of dimension 600×405×500 mm in humidifier for business class in Boeing 767). As a rule, two humidifier units are used for a long-haul plane. Each humidifier of CAIR system uses approximately seven litres of water per hour (100-150 litres of water per 10 hour in B767). Maintenance of the humidification system is minimal, it consists in changing the pad in regular intervals. As it is reported by the CTT Systems, CAIR system humidifiers increases level of relative humidity in the business class from 5% to 25% and in the economy class from 10% to 15%. According to Annual report 2004/2005 of CTT, 16 CAIR systems have been supplied to VIP aircrafts of type Boeing Business Jet, Boeing B767, B747 or Airbus A330, A340, A380 (in A380, only crew rest compartment is humidified). Let us mention that the principle of water surface humidification is also used in flight-deck humidifier of Hamilton Sundstrand [6] company.

2.3.2. Zonal drying, dual-flow ventilation system

The unsatisfactory cabin air humidity, however, is not the only humidity problem of the indoor environment of the plane. Over the ceiling of the cabin there always is an **intermediate** almost empty **space** (also called "crown area") which is exposed to the outside freezing temperature from above while its bottom faces the cabin. Since this space is not ventilated by the dry outside air, during the flight, there is always a strong tendency to water vapour condensation. The temperature in this space necessarily is far below the dew point and the condensed water tends to create ice layers on the airplane construction or sometimes to "rain" towards the cabin ceiling. Both these phenomena are dangerous – due to the extra weight of the ice or due to bringing up electrical system failures. Recently this high humidity discrepancy can be overcome by using the Zonal drying system of CTT Systems company. The system consists of a number of **zonal drier units** installed at strategic points in the aircraft. The units use a principle of Munters' dehumidifier. The dehumidifier uses a **desiccant** (silica gel) to remove moisture from the air. The desiccant is impregnated into a rotor made from glass fibre which is moving continuously through two streams of air taken from the crown area. The desiccant removes moisture from the first air stream (80%) thereby drying (dehumidifying) it. The air in the other stream (20%) is warmed and when passing through the rotating desiccant it removes the moisture from the desiccant. This moist air is recirculated in the cabin either directly or via the aircraft's air conditioning system. Thus, next to the prime aim of the Zonal drying system to dehumidify the crown area, it also helps to enhance the level of relative humidity in the cabin. According to Annual report 2004/2005 of CTT, 195 of Zonal drying systems have been supplied for the following aircraft types Boeing: B767, MD11, MD80, B737NG, B757, B747, BBJ, Airbus: A320/A321, A330, Bombardier CRJ-100/200.

2.4. Concluding remarks

A set of about fifty publications, reports and other sources were taken into account in this report. First of all the primary is the recognition what kind of cluster of involved problems is

[5] CTT Systems, http://www.ctt.se

[6] Hamilton Sundstrand, www.hamiltonsundstrandcorp.com

to create an artificial environment for human passengers in the cruising altitude of air transport where the climatic conditions are as incompatible with human being's needs. Despite the environment control system is as sophisticated as it is in modern airplanes the cabin environment may bring up an unfavourable impact or even health problems for a vulnerable part of passengers. Particularly complicated is the issue of relative air humidity inside the cabin and cockpit. On the one hand the intensive production of carbon dioxide necessitates an extremely efficient and powerful ventilation with a rapid air exchange, while on the other hand all the aboard electronic systems are endangered by air humidity in general because of the possibility of the dew point saturation. This danger is enhanced by the fact that the outside surface of the aircraft is exposed to temperatures as low as from -50 to -55°C. That is why the aircraft designers are very careful in admitting humidifying devices on board. The cabin air humidities ascertained during the monitored flights are strikingly low, sometimes lower than 5% of RH and therefore already from the nineties special humidifying devices have been developed. Two of their principles are in use nowadays, namely the steam-boiler based humidifiers and the surface-water-film based devices. Anyway it is clear from the investigated resources that the humidification problem consists rather in the issues of controlling the instantaneous humidifying performance and in a proper distribution of the conditioned air. This conclusion is in a good accordance with our research intents aiming at the modelling the air circulation and controlling the humidity control and distribution.

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This review introduces various physiological and environmental signals that might be interesting for the considered project. We describe the possible application for the project as well as the existing measuring methods. Finally we present commercially available sensors for each signal.

3. Bioelectrical signals

3.1. Background Information (General technology of measurement)

Bioelectrical signals are generated by nerve cells and muscle cells. Nerve cells control muscle cells by exchanging bioelectrical signals. In muscle cells the contraction is always accompanied by electrical signals. The source of these electrical signals is the membrane potential, which under certain conditions generates an action potential. For more information see [16].
Bioelectrical signals are measured with electrodes, either in an invasive or non-invasive way. For the invasive method, small hollow needles are placed directly inside the cell to measure the electric field generated by a single (or very few) cells. The invasive method is mainly used for measuring neuron activity and for very precise muscle cell activity measurements. Since invasive measurements are not feasible for the considered project, these signals are not further treated in this review [2].
The electrical activity of large tissues is the summation of many single action potentials. This signal can be measured in the immediate vicinity of the cells as well as further away on the body surface, because the electrical field is spread into the electro conductive medium of the body. The electric field can thus be measured non-invasively by placing electrodes on the skin. Usually these electrodes consist of metal. In order to improve electrical conductance, a gel is often applied to the electrode.
Since the bioelectrical signals measured from the surface of the skin are of very small voltage amplitude and of very high impedance, differential amplification with high voltage gain is necessary. During the measurement, the following problems may occur: Mismatches in electrodes' body interface parameters can lead to a DC bias. Additionally, if the subject moves during the recording, the electrodes have a bad contact to the skin surface. This will appear as rapid step baseline transition in the recording, which decays to the baseline value. Parasitic signals coming from the mains (220 V /50Hz or 110 V /60Hz) are also influencing the measured signal. Furthermore, so-called crosstalk may occur, i.e. a signal generated by a neighboring cell may influence the measured signal. Crosstalk can be reduced by carefully positioning the electrodes, or can be determined by cross-correlation.
Depending on the used method and the position, the measured bioelectrical signal reflects

- the nerve activity, measured by invasive methods only
- the brain activity, measured by the EEG
- the skeletal muscle activity, measured by the EMG
- the heart activity, measured by the ECG
- the eye movements, measured by the EOG.

In order to measure the brain activity, the electrodes have to be placed on the scalp, usually after abrasion of the scalp area and application of conductive gel to reduce impedance. Brain activity measurements (EEG) are therefore not further described. For measuring the eye movements, the electrodes need to be attached close to the eye which is very uncomfortable and thus not taken into account here.

The following subsections describe the measurement techniques and available sensors for skeletal muscle and heart activity (EMG and ECG).

3.2. Electromyogram (EMG)

3.2.1. General Background Information

The contraction of skeletal muscle cells is excited by the action potential of motor neurons. The contraction of a muscle cell is always accompanied by an electrical signal, because the membrane of the muscle cell depolarizes when stimulated by the motor neuron. Hence it is possible to detect the contraction simply by measuring the electrical signals generated by the muscle [16]. This is called an electromyogram (EMG). The typical repetition rate of a muscle unit firing is about 7 − 20Hz, depending on the size of the muscle, previous damage and other facts.

3.2.2. Impact on the passenger

To reduce thrombosis risk in an airplane, it is recommended to stand up and walk from time to time but also to move ankles and knees while seated [28]. By measuring the muscle activity it is possible to determine if and how much the passenger is moving and to give appropriate recommendations e.g. by the entertainment system.

3.2.3. Technology of measurement, commercial products

The EMG signal can be measured by applying conductive elements or electrodes to the skin surface. Surface EMG (sEMG) is the most common method of measurement, since it is non-invasive and can be conducted by an untrained person, with minimal risk to the subject. The measurement of the sEMG depends on a number of factors and the measured potentials of the sEMG signal vary from μV to the low mV range. The amplitude, time and frequency properties of the sEMG signal depend on factors such as:

- the timing and intensity of muscle contraction
- the distance of the electrode from the active muscle area
- the properties of the overlying tissue (e.g. thickness of overlying skin and adipose tissue)
- the electrode properties
- the quality of contact between the electrode and the skin

The raw EMG has a wide frequency spectrum (20−500Hz). Therefore 1000Hz or larger sampling rates should be used in recordings. The raw EMG may be used to determine bursts of activity and ”onset times”, and it is the best signal for examining problems like crosstalk or AC interference with the recording. However it is difficult to determine “levels” of muscle contraction. Therefore the raw EMG is often preprocessed by taking its absolute value (full-wave rectified EMG) before using it in further processing.
By taking the average signal on a window (averaged EMG) the level of contraction can be determined. In order to reduce the frequency content, the linear envelope EMG is often computed by low pass filtering (4 − 10Hz cut-off) of the full-wave rectified EMG. The linear envelope EMG is easy to interpret and it is useful to detect the onset of activity. But it is difficult to detect artifacts. Advantages of the linear envelope EMG are a reduced frequency

content of the EMG and thus lower sampling rates can be used (e.g., 100Hz) and less memory storage is needed. The processing can be done electronically and in real-time, but it adds a delay to the signal.
All errors explained above, mains interference (AC), DC-offset or DC-bias and crosstalk can occur in EMG recordings. ECG crosstalk (see section 3.3) occurs when recording near the heart, and will disturb the signal most, because ECG has higher voltages then EMG. There are many EMG sensors available on the market. Most of the manufacturers also provide a "data logger box" where the EMG sensors (and often other sensors) can be connected to. The data logger synchronizes and saves the data or transmits it directly to a computer. Most analysis software comes with the data logger to analyze the transmitted data.

Several EMG monitoring systems and sensors are listed below:

- **Biomonitor ME6000:**

  The Biomonitor ME6000 is a small and light weight (344 grams) EMG monitoring system. Mega Electronics Ltd. sells the Biomonitor ME6000 with 4, 8 or 16 channels which can be used to record EMG signals together with other sensor signals. Mega Electronics Ltd. offers the following additional sensors that can be connected to the Biomonitor ME6000:
    - Accelerometers
    - Gyro sensor
    - Goniometers (for angle measurements of e.g. wrist, ankle, elbow, neck)
    - Inclinometers (for angle measurements)
    - Heart rate
    - ECG preamplifier
    - Foot switches (for step detection)
    - Force sensors
    - Tidal volume sensor (respiration)

  All the recorded channels are synchronized with the EMG measurements, see http://it.uku.fi/biosignal/motion_lab.shtml.
  With the ME4ISO Isolation Unit it is possible to connect four adjustable, isolated external analog signals, as for example force sensors, force plates, isokinetic systems, etc.
- **Biovision EMG sensor:**

  The EMG sensor of Biovision is an active electrode, thus no further amplification is necessary. It can be connected directly to an analog digital converter. The amplifier is placed close to the electrodes to achieve high signal to noise ratio and allows artifact free measurements with a cable length up to 30 m. The amplifier has the dimensions 30×14×8mm, weighs without cable 12 gr and needs a power supply between ±2, 5 and ±15 V. For further information see http://www.biovision.eu/.
- **Delsys EMG sensor:**

  Delsys offers two different types of EMG sensors. One type uses two contacts while the other uses three in order to reduce EMG crosstalks. The electrodes can be fixed on the skin by an adhesive and thus no gel is necessary. The EMG sensors include a preamplifier and the input impedance is > 1015//0.2pF. The dimensions of the sensors are 41 × 20 × 5mm. For further information see http://www.delsys.com/Products/EMGSensors.html.

- **Biometrics EMG sensor:**

Biometrics offers EMG sensors that are usually used in conjunction with one of their data loggers (see http://www.biometricsltd.com/y%20research.htm). In addition to the EMG sensors, other types of sensors can be connected to the data logger. Biometrics states that no gel needs to be applied on the skin due to the very high input impedance of > 10, 000, 000M. Independently of how many EMG sensors are used, only one ground reference cable is required. The Biometrics sensors include a high-pass as well as a low-pass filter. The third order high-pass filter (18bB / octave) removes DC offsets due to membrane potentials. The low-pass filter (eighth order elliptic filter with -60bB at 550Hz) removes the frequencies above about 460Hz in order to prevent aliasing when the signal is recorded digitally by a computer. It is very important to remove these high frequencies when interfacing to a computer that is sampling the signal since they would be converted to a lower frequency and mixed with the original signal.

- **Nexus EMG sensor:**

Nexus offer reusable as well as disposable EMG sensors and appropriate cables with active shielding and carbon coating. The sensors are usually used in conjunction with one of Nexus' data loggers (see 2.5) and can also be used for measuring ECG. They come without amplifier. The amplification is performed within the data logger. This makes the whole system more flexible and cost-effective. The Nexus cables can be used to measure either EMG, EEG, ECG or EOG.

3.3. Electrocardiogram (ECG)

3.3.1. General Background Information

The electrocardiogram (ECG) could be called the "EMG of the heart". It measures the electrical potential between two points of the body. The ECG can be recorded at different positions on the body. To obtain the full information, several number of leads need to be considered (see [26] for more information). Figure 1.1 shows an ideal human ECG waveform of lead I and the associated features. The standard features of the ECG waveform are the P-wave, the QRS-complex and the T-wave which reflect the depolarization and repolarization of the heart muscle tissue. Additionally a small U-wave (following the T-wave) is occasionally present.
Changes in an ECG from the normal tracing may indicate one or more of several heart-related conditions. A systematic cardiological ECG analysis as described in [25] includes the following:

1. Measure the heart rate, generally expressed in beats per minute (bpm)
2. Determine the heart rhythm in order to detect disorders of the following kinds:
    - Arrhythmias (e.g. wandering pacemaker, atrial fibrillation, ventricular tachycardia, ventricular fibrillation)
    - Disorders in the activation sequence (e.g. premature ventricular contraction)
    - Disease of the electrical conduction system (e.g. Bundle-branch block, atrioventricular conduction block (AV-Block), Wolff-Parkinson-White syndrome)
3. Measure time intervals (QT-, ST- and PR-interval, QRS-width, ...)

4. Determine the electric axis of the heart
5. Detect increase in wall thickness or size of the atria and ventricles
6. Detect myocardial ischemia and infarction
7. Determine drug effect
8. Detect electrolyte imbalance

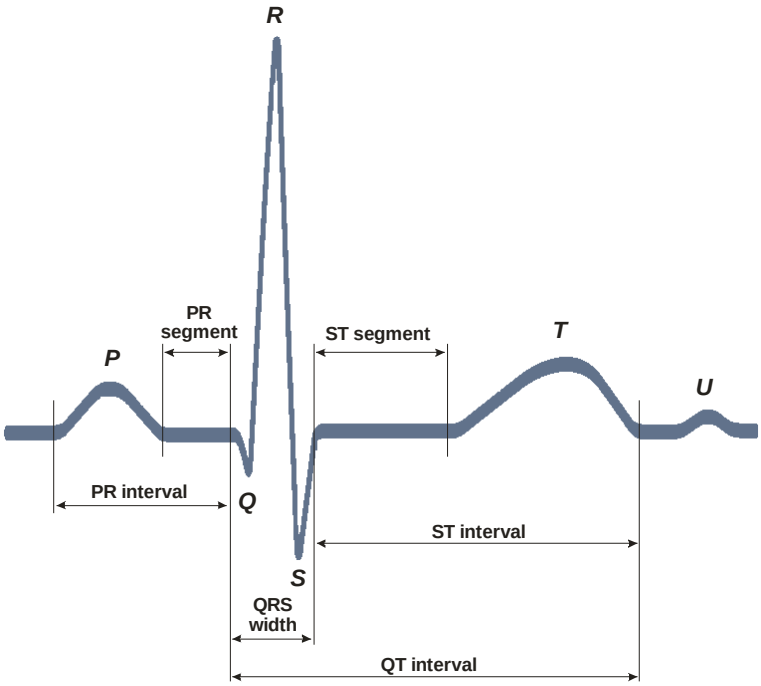

Fig. 1.1: The normal, ideal electrocardiogram consists of the P-wave, the QRS-complex and the T-wave, which is sometimes followed by an U-wave. Additionally the definitions of the different time intervals are given.

To give a precise diagnosis, many features of the ECG signal must be taken into account. For some diagnosis the cardiologist need several leads of the ECG (e.g. determine the electric heart axis) whereas for others one good lead can already be enough (e.g. measure the intervals).

The **heart rate** is normally the first feature determined out of the ECG. The heart rate is the number of heart beats per second. It is measured from the electrocardiogram (ECG) by using the RR-interval duration averaged over several heart beat periods. For a regular rhythm the heart rate can be expressed as one single value. Does the frequency change very fast, the minimal and maximal RR-interval duration (heart rate) is determined. If there are single longer time intervals, these are measured separately [25].

Usually the heart does not operate as stable as a pendulum. The heart rate changes from beat to beat. This is called the **heart rate variability (HRV)** and is a result of integrative neurohumoral influences. During normal sinus rhythm the beat of the heart is self-initiated by the sinoatrial node. This relatively constant frequency is modulated by different factors which add variability to the heart rate. Their effect can be seen when analyzing the HRV power spectrum.

Beside the RR-interval, the most important **intervals in the ECG** are the duration of the P-wave, the PQ-interval, the QRS-width and the QT-interval. According to [25] in normal sinus rhythm the

- P-wave has a duration of 50 − 100ms
- PQ-interval is 130 − 210ms
- QRS-complex has a duration of under 120ms (normally 60 − 100ms)

- QT-interval is between 260 − 400ms depending on the current heart rate.

3.3.2. Impact on the passenger

For the considered project the heart rate and the heart rate variability could be analized. According to [31], the frequencies in the HRV power spectrum can be classified into 4 components. The ultra-low frequencies of circadian rhythm and probably physical activity (≥5min cycle length, ≤0.003Hz). The very-low frequencies affected by temperature regulation (≥25s cycle length, 0.003−0.04Hz). The low frequencies reflecting sympathetic activity and probably parasympathetic activity (≥6s cycle lengh, 0.04−15Hz) and the high frequencies synchronized to the respiratory rhythm which are primarily modulated by parasympathetic activity (2.5 − 6s cycle lenght, 0.15 − 0.40Hz). The biological causes for the frequency components are in detail not well enough understood as divergent results in literature show. This field remains thus an active and important research field, needing new tools and methods.
Besides measuring health state, ECG measurements have also been used to determine the ”emotional and mental state” of a person. In [35] an ECG was taken from pilots during a real and as simulated flight with a BA Hawk MK 51. From the ECG the heart rate was calculated. It was shown that the heart rate changes significantly depending on the phase of the flight (e.g. rest, take-off, landing tour and landing). It is suggested that the heart rate changes reflect the changes in cognitive workload.
In [17], heart rate acceleration was measured (together with hand temperature and skin conductance) in order to distinguish between several emotions. They found that the autonomic nervous activity was different for anger, disgust and possibly sadness. Heart rate and heart rate variability might be used in the considered project to detect emotions like fear or stress.

3.3.3. Technology of measurement, commercial products

Similar to EMG, ECG is usually measured by attaching electrodes on the skin of the subject. However, new approaches without skin contact are being evaluated. One example is described in [34] where an ECG is measured by electrodes placed on a chair. The published results seem very promising. Another contact free approach is given in [20] where the heart rate is detected by micro-impulse radar. The contact free methods have so far not yet yielded measurements that comply with the quality requirements of medical applications. However, an approximate heart rate might be sufficient for the considered project and thus one of the contact free methods might be used. This would involve the development of a custom system since no commercial product is available yet.
Some systems used in clinical praxis record and store the ECG data but there is no real-time transmission and thus no online analysis possible. These systems are not covered here. In the following, we give an overview about various ECG measurements systems and sensors that allow online analysis.

- **Nexus ECG sensor:**

  The EMG sensor provided by Nexus can also be used to record an ECG.
- **Lifetronics:**

  The Fraunhofer-Institut für Photonische Mikrosysteme (IPMS) in Dresden is developing a telemedical healthcare system. The business field Lifetronics is focused on the development of innovative solutions for cardio-vascular monitoring in home treatment and fitness monitoring. Therefore the Fraunhofer IPMS has developed a Body-Area-Network. Medical sensors for ECG-, pulse- and blood pressure measurement are used for long term monitoring of patients. The 3-channel ECG is

recorded by a special ECG Foil, see http://www.ipms.fhg.de/de/products/lifetronics.shtml.

3.4. Galvanic skin response

3.4.1. General Background Information

Galvanic skin response (GSR) or skin conductance response (SCR) is a method of measuring the electrical conductance (resistance) of the skin. The impedance of the skin contains important information concerning its composition, blood volume, blood distribution, endocrine activity and also about the automatic nervous system activity.
The GSR is highly sensitive to emotions in some people. Already in 1937 Shock and Coombs found that skin resistance response varied as a function of affective intensity and affective valence [30], [14]. P. J. Lang found that GSR grows linearly with arousal ([29]. In [24] GSR (in conjunction with other physiological signals) was used to determine the stress level of a car driver.

3.4.2. Impact on the passenger

For the considered project, GSR might be used to detect negative emotions like stress, fear of flying, discomfort.
However, skin conductivity might not only change due to emotions but also because of the cabin environment. Since the air in the plane is very dry, the skin becomes dry and the skin resistance changes. This information might be used to give the passenger a feedback that he/she should drink something in order to prevent dehydratation and feel more comfortable. During a long flight it is recommended to consume double the amount of liquid that one would drink normally ([21]).
When the passenger is sweating, the skin is humid which changes the skin conductivity. GSR might thus also be used for individual temperature regulation.

3.4.3. Technology of measurement, commercial products

GSR is conducted by attaching two leads to the skin. It can either be measured actively or passively. If the active method is chosen, either a constant current is passed through the body and the electrical resistance is measured or a constant voltage is applied and the conductance is measured.
[14] claims that using the constant-voltage method produces more consistent results and should therefore be preferred. Passive GSR is performed by recording weak currents generated by the body itself.
To measure the GSR of a human body Nexus offers skin conductance sensors that can be used together with their data logger.

3.5. Bioimpedance

3.5.1. General Background Information

Bioelectrical impedance analysis (BIA) measures the impedance to the flow of an electric current through the body fluids. These body fluids are mainly contained in the lean and fat tissue. Impedance is low in lean tissue, where intracellular fluid and electrolytes are primarily

contained, but high in fat tissue. Impedance is thus proportional to body water volume (TBW). In practice, a small constant current, typically 800 uA at a fixed frequency, usually 50 kHz, is passed between electrodes spanning the body and the voltage drop between electrodes provides a measure of impedance. Prediction equations, previously generated by correlating impedance measures against an independent estimate of TBW, may be used subsequently to convert measured impedance to a corresponding estimate of TBW.
The impedance of a biological tissue comprises two components, the resistance and the reactance. The conductive characteristics of body fluids provide the resistive component, whereas the cell membranes, acting as imperfect capacitors, contribute a frequency-dependent reactive component. Impedance measurements made over a range of low to high (1 MHz) frequencies therefore allow development of prediction equations relating impedance measures at low frequencies to extra cellular fluid volume and at high frequencies to total body fluid volume. This is known as multi-frequency bioelectrical impedance analysis (MFBIA). BIA is a safe noninvasive method. [8], [9]

3.5.2. Impact on the passenger

Dry air inside the cabin leads to dehydration of the human body. It is interesting to investigate if the loss of water during a flight is measurable with common bioimpedance measurement methods and if sufficient drinking helps to avoid the problems caused by dehydration. [10]

3.5.3. Technology of measurement, commercial products

The most common way of BIA is with two electrodes at one wrist and two electrodes at one foot, so the impedance of the whole body can be measured. In the seat-project it would be more interesting to install the BIA electrodes in the two armrests, so only the impedance of the upper part of the body would be measured.
There are a lot of difficulties regarding a reliable BIA, for example the temperature change at the hand as well as the different constitution of the individual hands (horny skin) that influences the transition resistance. The following companies provide commercial BIA systems that are unfortunately not very small and cheap:

- Xitron: http://www.xitrontech.com/products.html
- Maltron: http://www.maltronint.com/portable_products.htm
- Tanita: http://www.tanita.com/IndexUS.shtml
- ImpediMed: http://www.impedimed.com/index.php?action=view&view=5841

3.6. Blood oximetry

3.6.1. General Background Information

Pulse oximetry is an optical method which is used to measure the oxygen level in the blood. Pulse oximetry actually measures the percentage of hemoglobin (Hb) which is saturated with oxygen. The oxygen saturation says how much oxygen the blood carries as a percentage of the maximum it could carry.
About 98% of oxygen in the blood combines with hemoglobin (Hb) to form oxy-hemoglobin (HbO2). The ratio of HbO2 to Hb in the blood is called percentage oxy-hemoglobin saturation (SpO2 or SO2). The total content of O2 in blood is directly related to SpO2 for any given Hb concentration, because the amount of O2 physically dissolved in the blood is relatively small. The typical range of SpO2 lies within 95 − 100%.

3.6.2. Impact on the passenger

The air pressure in an airplane is about the same as when being on a mountain at 2400 m altitude. Due to the reduced air pressure the oxygen saturation in the blood sinks. This was shown in a study by Cottrell et al. where the arterial oxygen saturation of 42 airline crew members was continuously monitored on 22 commercial flights. Mean oxygen saturations fell from 97% to 88.6%. However, variations between individuals were large (from 93% to 80%) and thus some of the subjects experienced a mild hypoxia (desaturation). In a study into health of aircraft cabin environments performed by the Building Research Establishment (BRE) in the UK [19], the authors comment that given the test group was composed of crew members only, it is likely that their average level of health and fitness would have been greater than for the general traveling public. Thus the risk of hypoxia might even be higher for passengers.
The study of the BRE [19] also mentions a paper by Flynn which deals mostly with altitude sickness as a consequence of mountains. However, the author argues that the mild levels of hypoxia that even cabin altitude can produce may be enough to bring about subtle changes in mental status, particularly in at-risk groups. These changes include cognitive impairment and may even stronger in travelers who are drinking alcohol or smoking cigarettes. This can lead to erratic behavior and loss of impulse control.
Additionally the BRE study mentions fatigue, mild hyperventilation, headache, insomnia or digestive dysfunction as possible consequences of mild hypoxia. All these symptoms impair the comfort of the passenger and detection by means of SpO2 (and other sensors) might be helpful to increase passenger's comfort and health.

3.6.3. Technology of measurement, commercial products

SpO2 can be measured optically, because the absorption of infrared light is very dependent on the SpO2, whereas red light is less dependent of this value. Therefore two light-emitting diodes, one with red (e.g. 660 nm) and the other with infrared (e.g. 940 nm) light are used to illuminate a tissue, such as a fingertip. The ratio of the light intensity as detected on a corresponding photo-detector diode can be used to calculate the SpO2 value. This method is referred to pulse oximetry and is nowadays the standard non-invasive way of estimating the SpO2. The emitter (LED) and receiver (photodiode) can be placed either side by side on the surface of the tissue, or on each sides of the tissue leading to the two techniques: reflectance and transmittance.
The transcutaneous reflectance oximeter has the advantage to allow monitoring of SpO2 transcutaneously at various locations on the body surface, including more central locations such chest, forehead, limbs, that are not accessible via trans-illumination oximetry.
It is important to note that this two-wavelength oxygen saturation measure works only with the hypothesis that only oxy-hemoglobin and reduced hemoglobin is present in the blood. The presence of carboxyl-hemoglobin (hemoglobin combined with carbon monoxide), methemoglobin (oxidized hemoglobin) or other dysfunctional hemoglobin affects the measurement.
The optical blood oximetry also presents important errors due to light attenuation by tissue and blood absorption, refraction, and multiple scattering. Additionally differences in the properties of skin and tissue, variation from individual to individual in attenuation of light causes calibration problems.
Problems with both transmission and reflectance oximetry include poor signal with body movement. There are several causes to these artifacts. Body movements modify the physiology of the tissue under gravity and probe pressure on the skin. Layers of the sensed tissues may be modified by small muscle or nerve activities induced by strain or stress. The light probe-tissue coupling may

be modified through the time by displacements of the probe on the surface of the sensed tissue. Therefore motion artifact cancellation techniques are of primary importance for SpO2 monitoring [12], [18], [22], [23].
The following three companies offer commercial products for measuring the blood asymmetry in a human body:

- Nonin OEM module: http://www.nonin.com
- LifeGuard: http://lifeguard.stanford.edu
- NeXus: NeXus offers a blood oximetry sensor that can be connected to their data logger, see http://www.mindmedia.nl/english/sensors.php

3.7. Blood pressure

3.7.1. General Background Information

Blood pressure is the pressure of the blood against the walls of the arteries. The higher (systolic) number represents the pressure while the heart contracts to pump blood to the body, whereas the lower (diastolic) number represents the pressure when the heart relaxes between beats.

3.7.2. Impact on the passenger

Blood pressure less than 120/80mmHg (millimeters of mercury) is considered optimal for adults. A systolic pressure of 120 to 139mmHg or a diastolic pressure of 80 to 89mmHg is considered “prehypertension” and needs to be watched carefully. A blood pressure reading of 140 over 90 or higher is considered elevated (high). Within the SEAT-project blood pressure could be monitored for high risk groups.

3.7.3. Technology of measurement, commercial products

Non-invasive blood pressure is performed in standard medical practice using a sphygmomanometer placed on the upper arm or on the wrist, although most physicians do not consider the wrist measurement sufficiently reliable. The automatic oscillometric methods, also called ambulatory blood pressure monitoring (ABPM), is functionally the same as for the auscultatory method (manual, using a stethoscope and a cuff), but with an electronic pressure sensor (transducer) fitted in the cuff to detect blood flow, instead of using the stethoscope and the expert’s ear.
The cuff is inflated to a pressure in excess of the systolic blood pressure. The pressure is then gradually released over a period of about 30 seconds. When blood flow is nil (cuff pressure exceeding systolic pressure) or unimpeded (cuff pressure below diatolic pressure), the cuff pressure will be essentially constant. When blood flow is present, but restricted, the cuff pressure will vary periodically in synchrony with the cyclic expansion and contraction of the brachial artery, i.e. it will oscillate. The cuff pressure at which oscillations start is the systolic pressure; pressure when oscillations cease is diastolic pressure. The cuff method is a non-continuous measurement method.
The volume-clamp method allows a non-invasive continuous blood pressure measurement. The blood pressure is usually measured in the finger where the diameter of an artery under a cuff wrapped around the finger is kept constant (clamped), in spite of the changes in arterial pressure during each heart beat. Changes in arterial diameter, detected by means of an infrared photoplethysmograph built in the finger cuff, are opposed by a fast pressure servo

controller that changes pressure in an inflatable air bladder, which is also mounted in the finger cuff. The cuff pressure thus provides an indirect measure of intra-arterial pressure.
There are many measurement systems that doctors also use, but they do not allow continuous monitoring. Products that allow continuous monitoring are:

- **Portapres Blood Pressure:** (http://www.finapres.com/customers/portapres_conf.php)

  Portapres is a portable device for blood pressure measurement, based on an advanced noninvasive blood pressure measurement technology. It measures finger arterial pressure and heart rate and reconstructs brachial arterial pressure. There exist a automatic two finger switching system to avoid patient discomfort and venous congestion. Thanks to the analog output, the Portapres system can be integrated in any custom solution.

- **Lifetronics extension:**

  The Plethysmography-Sensor belongs to the Lifetronics system. It measures the finger pulse and in conjunction with the ECG-foil long-term non-invasive continuous blood pressure monitoring is possible. The continuous non-invasive blood pressure measurement follows the approach of Barschdorf and Erig. It is based on the delay of the blood-wave from the heart to the finger [13]. The ECG-foil represents the second sensor in this application. The blood pressure values are stored in the internal flash memory.

- **Nexus blood volume pulse sensor:**

  A blood volume pulse sensor can be used with the NeXus data logger. It measures the relative blood flow in the hands (fingers) with near infrared light (Photoplethysmography). From the pulse signal also heart rate and heart rate variability could be calculated.

3.8. Respiration

3.8.1. General Background Information

The respiratory system consists of the lungs, the conducting airways (trachea, bronchi, bronchioles, alveoli), pulmonary vasculature, respiratory muscles, and surrounding tissues and structures. The breath rate has an influence on the heart rate - the so called respiratory sinus-arrhythmia.

3.8.2. Impact on the passenger

One use of breath rate measurement for the project might be to detect if the passenger is sleeping and thus does not want to be disturbed.

3.8.3. Technology of measurement, commercial products

Among the techniques of unobtrusive respiration measuring most are based on measuring the changes in throatic volume as well as changes in relative volume between ribcage and diaphragm (via abdominal motion). Referred to spirometry (the classic pulmonary function test, which measures the volume of air inspired or expired as a function of time), the errors are 5 to 10%. Measurement artifacts are caused by body motion.
The following unobtrusive respiration measuring techniques exist:

- **Strain gauges:**

  The respiration measurement with strain gauges is a mechanical measurement. Strain gauges are wrapped around the torso. By measuring their diameter breathing can be monitored. Piezoresistive techniques are mainly used in this case. This is interesting since piezoelectric materials can be embedded in clothes and this type of sensors does not require current injection in the body to perform the measurement.
- **Inductive plethysmography:**

  Respiratory inductive plethysmography (RIP) is a biomagnetic method. It employs a pair of wires, each attached in zig-zag pattern to its own highly compliant belt. One belt is placed around the ribcage and the other around the abdomen, so that each wire forms a single loop, and the pair is excited by a low level radio-frequency signal. Changes in the loop cross-sectional area produce corresponding changes in self-inductance. The demodulated signal provides a signal proportional to the chest wall that is encircled by the loop. Since movements of the respiratory system are dependent on both ribcage and abdominal excursions, it is necessary to place inductive plethysmographic sensors around both these compartments.
- **Impedance plethysmography:**

  Impedance plethysmography is performed by injecting a current to the skin by two electrodes. This is rather uncomfortable and thus not further treated here.

Commercial systems to detect blood pressure are:

- Lifeguard: http://lifeguard.stanford.edu/
- g.MOBIlab: http://www.gtec.at
- NeXus: NeXus offers strain gauge sensor for respiration that can be connected to their data logger, see http://www.mindmedia.nl/english/sensors.php

3.9. Bioacoustic signals

3.9.1. General Background Information

Some biomedical phenomena create acoustic noise, for example the flow of blood in the heart, through the heart's valves, or through blood vessels generates typical acoustic noise (e.g. used for the blood pressure measurement method with a stethoscope). Also the flow of air through the upper and lower airways and in the lungs creates acoustic sounds, known as coughs, snores, chest and lung sounds. Sounds are also generated in the digestive tract and in the joints.

3.9.2. Impact on the passenger

In order to measure bioacoustics' signals, the microphone must be attached to the body surface, but in a convenient way. One possibility would be to integrate a microphone in an earplug-headphone and measure the bioacoustics' signals while no sound is played by the headphone. Breath and signals related with the lungs might be detected in this way. By measuring heart sounds it is possible to determine the heart rate without measuring the ECG. However, the noise generated by the airplane is usually quite load and will drown the low sounds.

3.9.3. Technology of measurement, commercial products

Since the acoustic energy propagates through the biologic medium, the bioacoustic signal can be acquired on the surface of the body, using acoustic transducers (microphones or accelerometers).
The same requirements are needed in the sector of hearing aid development, where also very small microphones are needed. For example Knowles Inc. is a famous company that produces microphones for hearing aids, see http://www.knowles.com/knowles.com/pressdetail.jsp?id=11 and, http://www.knowlesacoustics.com/

3.10. Body temperature

3.10.1. General Background Information

There are two types of body temperature that have to be distinguished:
1. The central temperature is determined with a core temperature measurement, usually performed in the rectum or oesophagus.
2. The peripheral temperature is skin temperature. The body shows isothermal curves with increasing temperatures towards the chest (ankle, forearm or finger skin temperatures are lower than 30◦C because of vasoconstriction).

3.10.2. Impact on the passenger

The body core temperature provides information about the physiological state of the individual. Increased ventilation, perspiration, and blood flow to the skin result when the individual has high fevers.
Some people get cold hands when they are freezing. It has to be investigated if skin temperature can be used to improve cabin temperature regulation in an airplane.

3.10.3. Technology of measurement, commercial products

The specific site of body-temperature recording must be selected carefully so that it truly reflects the desired temperature which should be measured. The skin or oral-mucosa temperature of a subject seldom reflect true body-core temperature. From radiation theory, the spectral distribution of the radiation depends on the temperature of the body. From that, the temperature of the body can be deduced from the radiance measured at a given spectral wavelength.
One of the most common thermal detectors used in the infrared (IR) applications is the thermopile. Thermopile detectors are voltage-generating devices, which can be thought of as miniature arrays of thermocouple junctions. Body temperature does not vary rapidly and thus does not require temperature-measuring device with fast response.
Ear located IR emission detection for temperature measurement has been proposed and quite widely accepted as a reliable estimate of core body temperature [15],[32]. The IR ear thermometer basically works by detecting IR energy emitted from the deep auditory canal and tympanic membrane. This body site is physiologically appealing because the tympanic membrane shares arterial blood supply with the hypothalamus; the body's temperature control centre. The temperature of the tympanic membrane is recognized as a core body temperature. The advantages to IR devices over traditional thermo-meters are rapidity of results, efficiency,

patient comfort, lack of external influence (e.g., hot or cold liquid ingestion, tachypnea, gum chewing), no mucous membrane contact, minimal contraindications and it is a non-invasive procedure.

In the following different commercial system that measure the temperature are listed:

- **NeXus:**

  NeXus offers a skin temperature sensor that has a resolution of 0.0001 degrees. It can be applied on the hands or on another part of the body.
- **Ear thermometer:**

  There are various commercial products available to measure body temperature in the ear by an IR sensor, e.g. http://www.braun.com/global/products/healthwellness/earthermometers/thermoscan.html. But these do not allow continuous monitoring of the body temperature. A custom solution might be necessary for continuous measurements.
- **Infrared camera:**

  The body temperature might also be monitored by an infrared camera, e.g. http://www.flirthermography.com/germany/infrarot/infrarot-kamera.html. However, these cameras are usually used for process control and are rather expensive.

3.11. Pressure

3.11.1. General Background Information

Pressure is an entity to quantify the force per area that is executed on an object. In this chapter we don't focus at the pressure in fluids or gases but at the pressure from objects.

3.11.2. Impact on the passenger

The pressure distribution on the seat could be used to assess the passenger's comfort and to manipulate the seat controls accordingly.

3.11.3. Technology of measurement, commercial products

There are several ways to measure pressure, e.g. piezoresistive or capacitive [33]. Mostly, the piezoresistive sensors consist of resistance strain gauges included in a membrane. If pressure is applied to the membrane, the resistance of the strain gauges changes and thus the measured voltage. These sensors are cheap and very sensitive, but the used materials are strongly temperature dependent. Out of this reason such sensors sometimes include a temperature sensor to correct the pressure data. Another problem with resistive sensor occurs when the input lead of the sensor is bended (which would happen on a seat). Then the resistance changes which distorts the measured value.
Capacitive pressure sensors are not affected by bended input leads. The functional principle is the following. When pressure is applied to a capacitor, the distance between the two plates and thus the capacity changes which can be measured.
In the following, a list of commercial products for pressure distribution measurement as well as a textile pressure sensor developed at the Swiss Federal Institute of Technology, is presented.

- **Textile pressure sensor:**

At the Swiss Federal Institute of Technology a textile capacitive pressure sensor was developed [27]. It has the advantage that it is relatively cheap in manufacturing. In the future an array of these sensors should be used for decubitus prevention.

- **Conrad Piezoresistive Sensors:**

  Conrad offers very cheap piezoresistive pressure sensors, see http://www1.conrad.de. However, the sensitivity range has to be verified and the temperature dependence investigated.

- **Novel, Pliance Pressure Sensor Mat:**

  Sensor mats are in general very accurate but also expensive. They are mostly used in clinical practice. Novel offers their Pliance pressure sensor mats with up to 12'000 sensors and a data rate of 10'000 sensors/s. They also offer a special mat for car seats, see http://www.novel.de/ger/productinfo/systems-pliance-carseat.htm

- **TactArray PPS sensor array Pressure Profile Systems Inc.:**

  PPS offers a sensor array that can be stretched up to 10% without loosing performance which would be ideal for cushions. The sensor array can have a resolution of 10 or 25mm and it can cover areas up to 50cm x 40cm. Maximum pressure is 35N/cm2. http://www.pressureprofile.com/ tactArrayType.php?type=stretchable

- **XSENSOR:**

  XSENSOR offers a capacitive pressure sensor array on a tissue that can be used for example on seats or mattresses. http://www.xsensor.com/index.html

- **GB SoftMess:**

  GB SoftMess is a sensor mat similar to those of XSENSOR and Novel. They are also designed for chairs and mattrasses. http://plath.info/Vorschau/gego/index.php?comp=0&lang=de&dyn=1&link_gr=druckmessung&link_id=6

4. Environmental Sensors

4.1. Light

4.1.1. General Background Information

Light is electromagetic radiation with a wavelength that is visible to the eye (visible light). There are no exact bounds to the visible spectrum; a typical human eye will respond to wavelengths from 400 to 700nm. [11]
For the SEAT-project there are two useful measurements of light:

1. The illuminance of the cabin environment and of the seat environment specified in lux

   = lumen/(m^2)

2. The luminance specified in cd/(m^2).

The illuminance is the luminoux flux per unit of area, whereas the luminance is the energy that is absorbed as a visible light from the eye, which means the impression of brightness of an area. [1]

4.1.2. Impact on the passenger

The impact of light to the comfort of the passenger gets evident in two extreme light-depended situations: sleeping and working. During sleep there has to be a dark environment, which means possible light from the floor and neighbors has to be shielded and in opposite the passenger has to be illuminated during reading or working tasks. In-between there are situation such as resting or watching TV, where the light has to be smoothly controlled.
The physiological comfort can be influenced and improved by choosing agreeable ambient light, whereas the color of the light plays an important role in points of subjective reception of the light. According to [1] green and blue light has a tranquilizing effect, whereas for example red, orange, yellow, brawn and violet is more disquieting and stimulating.

4.1.3. Technology of measurement, commercial products

In order to measure the illuminance and the luminance there are different measuring principles and various commercial sensor technologies available. The most common measuring principle works with a photodiode that converts light into an electrical current. Due to the fact that the physical principle of the measuring methods is not relevant for the project issue, this report has just a short look at different light measuring applications that could be interesting for the project. These measuring applications could be realized with the following two ways of implementation:

1. Use of a photodiode integrated in a self-designed circuit board
2. Use of a commercial luxmeter connected to a processing unit

The advantage of using a photodiode is the flexible and smaller layout of the design, whereas the quality and reliability of the self-designed measuring device is probably not as high as a commercial luxmeter.
Following there are two examples of different commercial luxmeter listed:

- Mavolux 5032 C/B USB: http://www.gossen-photo.de/english/lichtmess_produkte.html
- Luxmeter LX1010B: http://www.multimeterwarehouse.com/FX101f.htm

4.2. Sound

4.2.1. General Background Information

Humans can generally hear sounds with frequencies between 20 Hz and 20 kHz although this range varies significantly with age, occupational hearing damage and gender; the majority of people can no longer hear 20,000 Hz by the time they are teenagers, and progressively lose the ability to hear higher frequencies as they get older. In an airplane sound can be divided in three different aspects:

- environmental disturbing sound
- entertainment sound
- conversation/voice

The first two aspects can be grouped in passive sound and the last one in active sound.

4.2.2. Impact on the passenger

The impact of the environmental sound to the passenger is easier to describe than the impact of the light. In an airplane it is in every situation, except of a loudspeaker announcement from the captain or the stewardess, desirable that the passenger isn't disturbed by environmental sound. So he should be shielded as good as possible from this kind of sound. The entertainment sound is a non obtrusive but desirable sound.
The active sound (voice) produced by the passenger during a conversation could be interesting for the project. Analyzing the voice enables the possibility to evaluate the emotional state of the passenger or the overall social well-being in the airplane. A very recent approach in this direction is described by Anmol Madan et al. at the Tenth International Symposium On Wearable Computers (ISWC2006) in the article VibeFones: Socially Aware Mobile Phones [4].
Listening to ourselves we notice that we often express our feelings by talking. Sometimes the emotional information is not only in what we say but in the tone of voice. Dimensional emotion theories use dimensions rather than discrete categories to describe the structure of emotions. [3] used the three dimensions activation, evaluation and power. He states that ¨most acoustic variables correlate with activation, in the sense that expression of active emotion is accompanied by higher F0 (F0 corresponds to the voice carry frequency) mean and range, longer phrases, shorter pauses, larger and faster F0 rises and falls, increased intensity, and a flatter spectral slope.¨ It is highly probable that comfort or discomfort in an airplane will provoke emotions that will also be expressed during conversations with the seat neighbor or the air hostess. However, negative emotions may not only come from discomfort. Thus, if negative emotions are detected from voice features, it has to be determined where these negative emotions come from.

4.2.3. Technology of measurement, commercial products

For the passive sound a simple conventional microphone placed near the head of the passenger should be adequate. A microphone is a device made to capture waves in air, water or hard material and translate it to an electrical signal. The most common method is via a thin membrane producing some proportional electrical signal. Nowadays most microphones use electromagnetic generation (dynamic microphones), capacitance change (condenser microphones) or piezoelectric generation to produce the signal from mechanical vibration. [6]
For the analysis of the voice of a passenger a microphone should be adjusted in such a way that it focuses only on the voice of the individual passenger. Therefore an array microphone,

as proposed from *"fortemedia"* [5] could be useful. An array microphone is able to isolate a sound source and suppressing ambient noise and reverberation.

4.3. Cabin-Pressure

4.3.1. General Background Information

Due to the fact that an aircraft reaches altitudes where the natural atmospheric pressure is too low to allow people to absorb sufficient oxygen, cabin pressurization is made. This means that air is pumped into the cabin of an aircraft to increase the air pressure within the cabin. So during a normal flight the air pressure inside the cabin reaches more or less 756 hPa, to comparison at sea level the air pressure is 1013hPa. [7]

4.3.2. Impact on the passenger

The low pressure in the cabin leads to a lower level of oxygen saturation in the blood, see chapter 3.6.

4.3.3. Technology of measurement, commercial products

The cabin pressure is already in every airplane continuously controlled. Due to the fact that the pressure for one seat can't be controlled individually but only global for the whole cabin it is not necessary to build an air-pressure system in every seat. For the research proposes in the different laboratories a normal commercial barometer should be sufficient.

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5. PHYSIOLOGICAL MONITORING

5.1. MEDICAL MONITORING SYSTEMS

Medical monitoring is a fast developing area that is gradually moving towards intelligent monitoring systems. There is various level of understanding for the different physiological signals as some techniques such as ECG have accumulated a lot of knowledge and expertise in understanding the cardiac condition while others are in their very infancy. Some of the new developments in the medical fields are presented in the next sections.

5.1.1. Heart Monitoring

Heart monitoring has started in the seventies when the pace makers were introduced. A lot of progress has been made since then as the computers have become an integral part of the monitoring system.

An example of such system is Medtronic, an Internet-based, remote cardiac device monitoring system. According to the company, physicians now can offer the Medtronic CareLink Network to more than 130,000 persons whose heart conditions are being monitored. The company recently received US Food and Drug Administration approval to allow use of these implantable devices with the Medtronic CareLink Monitor, which patients use at home or while traveling to transmit data to their clinics. Patients transmit data from their ICD or CRT-ICD using a portable monitor that is connected to a standard telephone line as instructed by their physician. The information, which is comparable to the information provided during an in-clinic device follow-up visit, provides the physician with a view of how the device is working. If needed, the physician can adjust the patient's medication or prescribe additional therapy.

The InSync II Marquis system, available in the United States since August 2003, helps recoordinate the beating of the heart with features that can be tailored to individual patients, such as the ability to independently program the level of energy delivered to each ventricle. It also can painlessly terminate up to 75% of fast ventricular tachycardia episodes with antitachycardia pacing instead of delivering unnecessary shocks, while also providing effective defibrillation protection when necessary.

Meanwhile in Soth Korea a remote system was developed to enable fast recovery and better quality of life for patient. The authors are developing an integrated telemonitoring system for artificial heart. In addition to instant signal monitoring function, a structural database of patient's whole physiological and device signal data that can be accessed through either world-wide-web or direct mobile database mirroring, an integrated data collector that connects to implanted controller and to patient monitor and other physiological signal monitors, and a portable monitor with mobile Internet connection and a machine intelligence engine for basic diagnosis of device status for patient's outdoor mobility The machine intelligence engine provides device related information such as pump flow and arterial pressure estimated from device internal signals and basic diagnosis of device status using fuzzy neural-network based rule-base.

Another interesting development is a wireless, remote monitoring system for newly developed wearable pneumatic ventricular assist device (VAD). Developed monitoring system consists of Bluetooth and code division multiple access (CDMA) communication hardware and related communication programs. Bluetooth communication is used for short distance detailed monitoring and CDMA communication is used for long distance simplified monitoring.

Overall the trend for system intervention is evident although the progress has been relatively slow.

5.1.2. Motor Activity Monitoring

With a new trend for improvement the quality of life of the elderly population and reduction of the social burden for more and more elderly care homes, a big emphasis has been placed on the development

A multisensor home monitoring system has been developed within a telecare project to help elderly people by observing mobility changes indicative of abnormal events. The motor activity data (in bed, getting up, getting out, visiting the toilets) are analysed from a statistical perspective to assess changes in occurrence, time and duration. Changes in activity data and correlations between in-bed restlessness and getting up variables show interesting trends in the behaviour of elderly people and can be used by the system as a predictive tool in abnormal situations. The objective of the telecare project is to build an abnormal event diagnosis system to help elderly people living alone.

The multisensor monitoring system consists of 10 infrared sensors on the ceiling of an elderly 'housing' in an institution connected to a PC by means of a communication network in its wire version (RS485). An analog-to-digital conversion board, an ADAM acquisition card and a serial link (RS232) supplement the system. Each sensor covers a zone. When the person moves, the sensor of the zone is activated but one or more devices may be triggered, due to adjacent sensors. The PC collects data that consist of sets of 10, 0 or 1 bit(s) according to sensor status followed by the date of the event. Each line of data identical to the previous one is deleted to optimize storage.

Such systems allow remote observation and early alert but have limited scope to provide appropriate responses.

5.1.3. Blood Pressure Measurement and Monitoring

Blood pressure is one of the more difficult method for implementation outside hospital environment. Measurement of blood pressure by a trained observer using a mercury sphygmomano-meter is accepted as the gold standard, but there has been an increase in the use of automated devices employing the oscillometric technique. Not all such devices have been clinically validated, and some do not carry an appropriate CE mark. A recent survey assessed the state of the European Union market for automated non-invasive blood pressure devices in terms of information provided by companies relating to compliance, validation and intended use.

It seems quite feasible to implement blood pressure monitoring by obtaining passenger's consent as an increase in health awareness among the population has led to an interest in self-monitoring of blood pressure. In Germany, for example, approximately 1.2 million automated devices are sold annually, many to members of the public for their personal use.

A survey was carried out between August 2002 and February 2003 identifying a total of 116 different companies considered to be active in the manufacture or supply of NIBP self-measurement devices. This survey assessed the existing devices and found some problems in terms of accuracy and reliability. The standard recommends, but does not require, manufacturers to follow one of three test methods. European standard EN 1060 part 4 is a new standard test method; the system accuracy clause of EN 1060 part 3 still applies.

Manufacturers are not required to measure system accuracy to one of the recognized protocols or standards to obtain a CE mark.

From the responses, and from details gathered from other sources, a total of 158 different models of the NIBP device were identified. Of these, 116 were automated devices intended for use on the arm or wrist, and 42 were other types of device that were excluded from further analysis as they were outside the scope of the study (4 were devices worn on the finger, 22 were patient monitors or defibrillators and 16 were ambulatory NIBP monitors).

For the 116 devices in our main category, totals were calculated for (1) the number for which completed questionnaires were received; (2) the number of devices of part (1), which were CE marked to the MDD; (3) the number of devices of part (2) for which clinical validation was claimed and (4) the intended use of devices of part (2), grouped into 'diagnostic and trend', 'trend only' or 'no claim', where trend was defined as the ability to detect pressure changes with no specific claim for the accuracy of absolute pressure. Devices for which the intended use was claimed as diagnostic, but not trend, were classified as 'diagnostic and trend' as the former implies the latter. Some respondents may have interpreted 'trend' as the ability of a device to store previous measurements. Claims for intended use were taken from returned questionnaires and from any other material (sales literature or specifications) that was supplied by each respondent.

This survey identified 86 different companies that were involved in the supply of NIBP devices to the EU market. Of these, 35 responded to the survey and a further 51 were identified by other means. A total of 158 different models of NIBP device were identified as being available for purchase within the EU. Of these, 116 were our main category device, and 42 were other types of device (patient monitors, defibrillators, finger devices and ambulatory monitors), which were outside the scope of our study and were excluded from further analysis. Of the 116 main category devices, 54 were intended for use on the arm and 62 were intended for use on the wrist.

Of the CE marked devices, clinical validation was claimed for 12 (41%) arm devices and 11 (39%) wrist devices. The 23 clinically validated devices comprised eight devices for which a clinical validation study had been carried out on the same make and model (three of these validation studies were reported in peer-reviewed journals), and 15 devices for which the validation study was carried out on a similar model (eight of these studies were reported in peer-reviewed journals).

This study was a market survey of automated NIBP devices for use on the arm and wrist. Its objectives were to determine the number of devices on the market that were CE marked as medical devices, what was their claimed intended use, and which were clinically validated. It differs from, but is complementary to, previous surveys that have used simulators to measure the output of automated devices when presented with known oscillometric signals.

5.2. MULTI-SENSOR PATIENT MONITORING SYSTEMS

Protocol Systems Inc. introduced several new options for its Acuity patient monitoring system, including colour laser printing, color flat panel display, and the capability to network a greater variety of instruments. The QuikSigns patient monitor can be networked to either the Acuity system or hospital-based nurse call systems. The QuikSigns helps with monitoring blood pressure, heart rate, pulse oximetry, and temperature; it is designed for routine and "spot-check" vital sign recording for hospital and clinic settings. A networked Acuity system is capable of networking via a standard Ethernet local area network or wide area network consisting of ISDN, T1/T3, or ATM connections. Portable Propaq vital signs monitors, Modem Propaq monitors, Protocol cordless electrocardiography telemetry transmitters, and the QuikSign monitors can all be networked in the Acuity system.

Again the system is complementing the nurses work rather than taking over the patient care.

5.3. COMPUTER SYSTEMS AND DECISION MAKING

In a variety of medical applications computer systems are involved only indirectly in the decision making due to the nature of the medicine. They are to support the doctors and consultants but cannot respond independently as of now. It seems that inn medicine the only area that decision is left to computers is the diagnostics when there is a clear cut case. The systems employed are of limited "intelligence and rely entirely on the expertise of the developing team.

5.4. PSYCHO-PHYSIOLOGICAL ASSESSMENT SYSTEMS

Contemporary nursing practice needs reengineering to deliver its service effectively and efficiently. Using computer technology to support clinicians' decision making may be a parsimonious way to provide high-quality, patient-cantered, efficient care. An interesting approach to treatment where the patient is put in the centre of the decision forming process is presented by the authors of the PAINReportIt. They argue that Managing cancer pain efficiently and effectively requires a new paradigm, one that facilitates information processing between the patient and provider and enhances collaborative decision making about pain therapy. This is a significant departure from the traditional medical approach where the treatment outcome is of prime importance and patient needs come poor second.

Designed as an interactive, touch-screen method for pain assessment, PAINReportIt displays standardized on-screen instructions that show interactive practice examples for all the symbols used throughout the program. Screens also are designed to document pain medications used by the patient, demographic information such as age, gender, and marital status, and to query patients about their computer experience and perceived acceptability of completing the survey via the touch-screen computer. The program automatically records the interval between the appearance of the first MPQ screen and the completion of the last screen.

The PAINReportIt database has 21 tables. Among them, three are reference tables containing information needed to run the program, and the rest are used to save client answers. Data related to various pain parameters, demographic variables, and drug variables are saved into different tables. For example, there are three tables for saving data on pain: pain_intensity, pain_location, and pain_quality. This database structure not only speeds data saving and retrieval, but also

The feasibility and usability of the computerized PAINReportIt was tested in 97 general public and 106 hospitalized patients with cancer. Complete data reported elsewhere 6 are summarized here. Feasibility was calculated by the time required to complete the program, which was recorded using the internal clock of the computer. The hospitalized patients required 2.5 minutes longer (17 ± 7 min) to complete the PAINReportIt than the general public (14.5 ± 6 min). Usability was measured with a 13-item computer acceptability tool developed specifically for testing the program. The overwhelming majority of the subjects in both samples indicated that the touch screen was easy to use (93%), that the PAINReportIt was a good way to report all information about their pain (75%), and that they liked the program (84%).

The goal of the PAINConsultN program is to provide a concise summary of the pain data and evidence-based pharmacologic treatment plans to support the clinician's decisions regarding

management of the patient's pain. According to the PAINReportIt output and published cancer pain guidelines, the vision is for the PAINConsultN program to generate an algorithm-based consultation note with a list of analgesics that can provide improved pain relief for a specific patient. If the patient's PAINReportIt output indicates that the pain has been relieved, the consultation note acknowledges the appropriateness of the therapy plan and reinforces its consistency with pain guidelines. The progam uses an algorithm that was developed for a logic library of recommended treatment strategies. The PAINConsultN aims to provide documentation of the pain and evidence-based decision support for managing pain and delivering individualized care tailored to the patients' needs.

5.5. CONCLUDING REMARKS

The existing monitoring systems have been mostly in the area of medical care and their application to the current project has a limited scope as they are built to rely on accurate data, full knowledge of the monitored subject and highly restricted response mode. The approach is to create vast data bases and to constantly rely on human intervention. As appropriate or necessary this approach may be for medicine, it is highly unlikely to work for the smart seat project. Lateral applications such as sport, physics and exercise physiology should be utilised.

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