PORTABLE MONITORING AND LOCALISATION SYSTEMS FOR DISABLED PATIENTS

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ABSTRACT:

This paper focuses on the research of an effective combination of different techniques that could allow localisation and physical activity monitoring of disabled patients, would they either be in hospital or other known indoor environments or outdoor. One of the ideal solution for this kind of problem could be the integration of a GPS/INS system for localisation, data storage unit and GSM or radio transmitters/receivers. Such a solution is nowadays inapplicable due to strong limitations involved with high computation rate required by such systems *vs* poor elaborating capacity of portable micro controlled devices and other problems that would be met if it has to be "transparently" worn by disabled patients. Our research has evolved starting from the analysis of state-of-the-art of integrated INS/GPS solutions for other application fields and how could they be adapted and replaced with other technological solutions that would match both portability constraint together with rough localisation of patients, adding their physical activity data collection and alert messages generation if monitored subjects leave restricted environments. Strong attention has been kept on all the device constraints, medical institutions' exigencies and the development of a device that could have real world application at market competitive costs.

1. INTRODUCTION

Remote disabled patients localisation and their physical activity analysis are matters of high interest among medical-scientific communities. On one hand they allow human resources' optimisation, centralizing the monitoring task, on the other hand they make possible to transparently evaluate patients' mobility and rehabilitation therapies, preventing behavioural modifications due to direct observation. Assuming that 1 to 1 nurse-patient permanent observation is inapplicable, mainly due to shortage of human resources, especially when the patient leaves hospital or physiotherapy centre in order to continue his/her rehabilitation home, it would be of high interest to evaluate the autonomous degree of physical activity in unforced and theoretically unobserved patient. This kind of data gathering could lead to many sociological and statistical studies and analysis that could answer to many actually unresolved questions (e.g. "would a lighter prosthesis or a longer-life battery operating wheelchair help effectively a disabled patient to socialize and integrate more than a standard one?"). On the other side, monitoring the position of patients undergoing some kind of mental impairment (e.g. Alzheimer or other severe diseases), could be useful to prevent their escape from hospital building or home, alerting the personnel or relatives, advising them about the real-time patient's walked path so to ease the localisation's task, without the needing of permanent and constant observation. The work presented in this article considered medical and physiotherapy institutions' exigencies and evaluated different solutions, in order to develop an integrated and portable device that could answer to a wide range of requests. The project started trying to couple a combined portable Inertial/GPS unit together with a device with storage capabilities and GSM transmitter. Though such a configuration could theoretically answer to all the project's quests, the computation skills required did not match with the expected use of the device. The intrinsic difficulties related to the realisation of an integrated portable GPS/INS system, lead to the acquisition of alternative technological solutions that could help with indoor localisation task, where the GPS signal is unavailable, evaluating also recently developed integrated systems that can be of interest for this purpose (Wi-Fi, RFID, UWB etc.) and consolidated radio-based solution. Localisation's accuracy requested in this application isn't definitely a strict constraint, accuracy of meters is enough to locate the patient by sight, so the use of INS with all related calculation for extremely precise positioning, could be postponed to future developments.

The first version of this device has been developed and is actually under testing. It combines a 433 radio transmitter/receiver, GSM/GPRS and GPS modules, elaboration and storage units together with an integrated MEMS IMU (without path reconstruction tasks, but with aim to detect patient's freefall or persistent immobilisation), so to allow to meet portability needing and localisation skills, monitoring and data collection requests about disabled patients' behaviour and alarm generation. It's suitable for patients that can be either able to walk or on wheelchair. The following paragraph is dedicated to the project's description and requirement analysis and to introduce some paths to be followed for each of the tasks that the developed device should comply to. It introduces different scenarios and several thinkable solutions to fulfil most of the project's requirements. The third part describes the chosen comprehensive solution and the considerations that lead to adopt such a configuration. Performed tests are addressed to validate and refine commitments' requests, to verify that the developed device meets their requirements and to study and evaluate alternative technologies. Preliminary results are shown in fourth part. Open issues, future developments and potential improvements, when the available technology could grant improved performances are indicated in the fifth and conclusive paragraph.

2. STATE OF THE ART OF POSITIONING AND LOCALISATION TECHNIQUES

Basically, the ideal device that could be developed has to answer to a wide and heterogeneous set of tasks:

1. patient's localisation, potentially everywhere, indoor, outdoor and in particular environments where no GPS or radio signal is available (e.g. underground);
2. alarm generation if the monitored subjects leaves a confined area or if particular conditions are detected (freefall, persistent inactivity etc.);
3. physical activity monitoring and data collection at different aggregation levels (hours, days, weeks, months and the like);
4. mobile phone features as optional, In/Out calls and panic button with automatic emergency number calling.

The problem of pedestrian positioning has been afforded by different authors in latest years for different purpose. In Retscher and Thienelt (2004), Gartner *et al.* (2005) and Retscher (2005) a comprehensive review about this subject can be found.

The research group established a partnership with a local firm (KFT, Merone-Italy) specialized in satellite anti-theft systems for vehicles and related monitoring software that uses GPS/GSM systems and that is developing the use of inertial sensor for crash reconstruction in their integrated peripherals. While the potential state-of-the-art localisation device would couple an INS and a GPS system and some communication mean (radio 433 or allowed frequencies transmitting devices that would not interfere with medical appliances, or other technologies solutions such as WLAN, GSM/GPRS/UMTS) for bridging data to a monitoring op-centre, available compact size INSs are not suitable for this kind of task. Data processing is strictly required to be onboard, we cannot rely on an IMU that passes data to a docked station that would perform the number-crunching part, if the intention is to put up a scalar system, autonomous and generally applicable. If one of the project's targets would be the monitoring of a patient that could be home or elsewhere far from a dedicated PC, it's a wrong assumption to rely on the existence of the operative central. On the other hand, the computational requirements and the related power consumption for a GPS/INS system, permanently on and constantly at full elaboration rate, does not allow to follow the "onboard computation" direction. Actually available INS units are quite big and heavy, recently developed portable ones require to be connected to a powerful pc in order to send data that are only generated but not evaluated. Processing onboard requires heavy computational requirements and consequently long-life powerful batteries. Even among mainstream INS producer, such kind of product is not available, the smallest product appeared was as big as a backpack and quite heavy (e.g. Applanix POS/LS – about 20Kg), it is not being sold anymore and it wouldn't anyway have suited project's needing. The main drawback that occurs when not using INS for indoor environments, where the GPS signal is unavailable, is due to the fact that Inertial Navigation (Britting, 1971) is the only form of navigation that does not rely on external references (Grewal *et al.*, 2001). This means that localisation outdoor will be a GPS task and indoor techniques has to be chosen basing on the specific commitment's request. Though the analysis lead to a wide variety of solutions that could cover partially the different aspects of the problems that have to be solved: from common shop anti-theft barriers to avoid monitored persons leave certain corridors, to more complex devices; the development focused on three possibility that could adequately combine cost-effectiveness and performances. Particular attention has been given to the development of a solution that can be offered both to hospitals and to domestic environments. The evaluation of alternative techniques rather than radio signals has partially been postponed as a future development, since actually extremely precision navigation or positioning are not the focus of this task. Higher localisation accuracy that can be obtained by the use of UWB or infrared devices introduces many drawbacks and a overall cost increase unbalanced by the obtained benefits, this convinced to follow other paths. Even though in the same hospital some positive previous experiences have been conducted with the use of UWB for positioning and measure interaction between doctors and patients (Alippi *et al.*, 2005), time shortage was against a necessary hardware redesign. Whenever it will be possible, integration of Ultra Wide Band with this system will be matter of future works. An interesting upgrade could emerge when there will be available on the market cheap and low consumption WLAN modules for micro controllers. Contemporarily to the research that lead to this paper in fact, in the same hospital where our tests have been performed, a project of Wi-Fi LAN has been conducted by IBM. When future development will lead to reliable but cheap Wi-Fi micro controlled modules, most part of data flows and localisation algorithms could be developed. Actually we hadn't been able to find commercial devices that could suit our needs in terms of performances, dimensions and electrical consumption. In its definitive application, the system could be designed as a combination of the following components:

- an *op-centre* where even one only person can monitor the position and the activity of several patients;
- cabled or wireless radio 433 transmitter/receiver;
- mobile phones or PDAs where doctors or patient's relatives can receive information about the subject activity;
- the portable device to be given to the patients either securing it on his/her belt, sewn on garments in its smallest version or mounted on wheelchair if the subject cannot walk.

Three main scenarios have been worked out and an hybrid solution that could cover most of the project's quests have been assembled and tested.

The first solution has been called "wired solution". It's composed of radio receivers dislocated on the area that has to be monitored. The patient is given a radio transmitter that broadcasts its signal every few seconds. Some configuration must be performed: suitable receiver distance, transmitter power and receiver sensibility have to be chosen so that is possible to cover the widest area possible with the smallest number of receivers, each transmitter has to be grabbed by at least one receiver and not by more than 2-3, in order to allow a quite rough localisation. This is the cheapest solution regarding the hardware, since radio transmitters/receivers are actually widespread and technology is consolidated. The main drawback is that receiver network must be cabled to pass information to the op-center and the localisation is allowed only among "cabled zones". If localisation needs to be performed also outdoor a GPS receiver and a GSM/GPRS transmitter has to be added to the device given to the patient.

A second solution, dual to the first one, is composed of several radio transmitters that covers the hospital area and that can be attached without needing to be cabled. These receivers are programmed to transmit every few second their pre-programmed georeferenced position, so that the receiver given to the patient, combined with signal coming from GPS, has always GPS-like coordinates about where it is, either outdoor or in zone covered by the transmitter's emissions. A GSM/GPRS unit is then needed to broadcast device's position to the op-center. This solution allows also the GSM channel to be used to send other patient's vital parameters or indicators about his/her physical activity, monitored by some additional sensors such as inertial ones or other. The advantages compared with previous solution are due to the hardware limited costs and easy implementation (cabling is not needed). A calibrated emission transmitter could be installed in every hospital room, so that immediate localisation is possible. Drawbacks of this solution are that constant monitoring involves permanent GSM activity with related problems and costs. The ideal solution with working INS/GPS/GSM is nowadays not applicable, examples of GPS/INS units relatively portable actually available that made calculations onboard are big, bulk and heavy, in opposition to one of the main project's constraint that limits the dimension of the device to be portable and nearly transparent to the patient that will use it. For all proposed solution there is also an interesting "plug-in": with moderate customization effort, there is the chance to use also a website connected to the op-centre that allows to perform the patient's localisation task from almost every PC or PDA connected to the web.

This feature is already actually implemented on KFT anti-theft software and has been added to our system with almost no effort.

Figure 1 shows the comprehensive solution and its different operations strategies while the device is in presence of wireless radio transmitter, wired radio transceiver or is open air with GPS signal availability.

3. A REAL WORLD APPLICATION

This project has been developed and tested in cooperation with "Villa Beretta", an important Physiotherapy and rehabilitation hospital in Lombardia. After having carefully evaluated commitment's requirements, we focused the attention on 2 main points:

1. prevent patients to leave restricted areas, in detail the hospital itself and its surrounding park;
2. data collection about the patients' habit throughout the day.

The project started into a particularly critical hospital wing where hosted patients suffered of severe mental disease in addition to rehabilitation needing. Mission critical task, was to try to avoid that these patients leave their hospital wing without clinical personnel being informed about that. The wing to be monitored is basically a straight 110 m corridor with emergency exits on both ends and main access from hospital in the middle of it. Particular attention has been given to exit/access points.

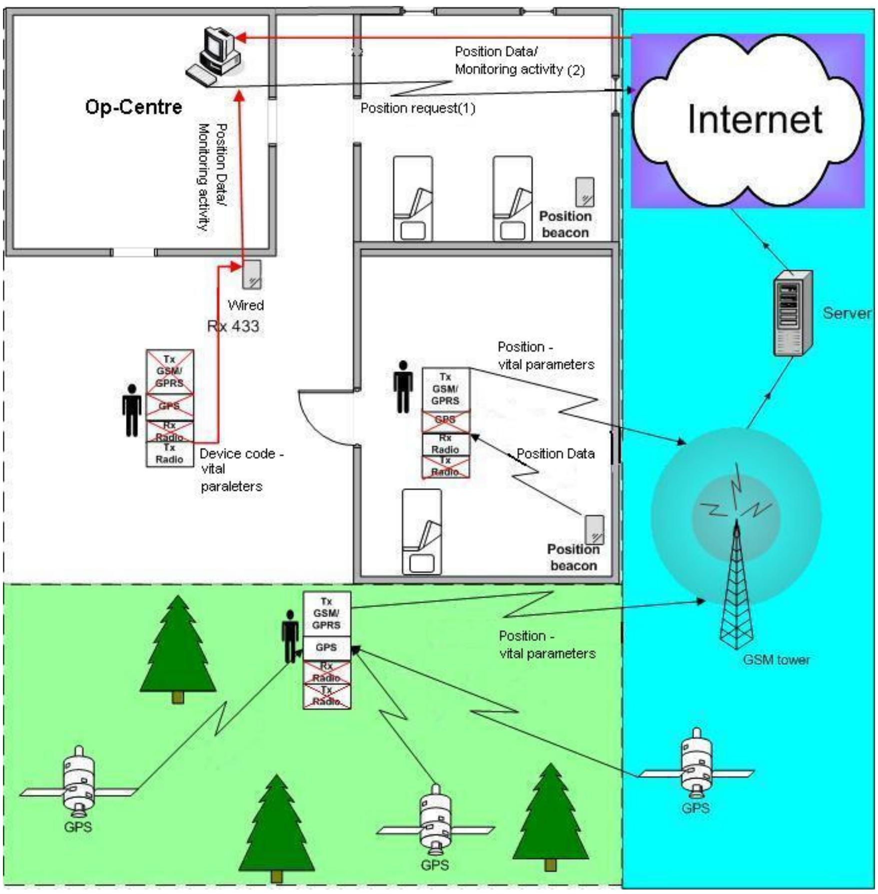

Figure 1. The man symbols represent patients and the column beside them, shows the capabilities of the monitoring device. An algorithm of context detection allows the device to activate the opportune means (GPS/radio 433 receiver/transmitter) to perform localisation and to transfer data to the op-centre (GSM/radio 433 transmitter).

The assistance/paramedical personnel is on duty 24/7 and highly dynamical, in the wing there is a personnel only accessible room with medicines, clinical patients' data and monitoring stations that was ideal for us to add our op-centre, since at least one person is always there and could be alerted by an alarm generated by the surveillance system. In first instance then, the initial installation was composed of: a laptop PC in the above mentioned room with proprietary op-centre software (*KFT-Centrale*) installed on it, an ILG (serial port GSM modem used to contact or for being contacted by patients' devices by GSM calls or SMS). Six radio 433 transceivers (*KFT-CDFull*) cabled to the laptop, communicating by mean of a serial cable and proprietary serial protocol (*KFT-KtCode*). Several compact radio transmitter (*KFT-BestIdea*) tested in first instance by nurses and doctors but that will be given to patients when the project will definitely be effective. Some completed peripherals (*KFT-KT200LinkMe*) integrating Fastrax ITRAX02 GPS module, Wavecom Q2406B GSM module, battery, antennas, speaker, microphone, panic-button, 433 transceiver and Motorola MC9608GB60 Micro Processor[1]. The IC of this device allows also to mount a triaxial accelerometer to perform the freefall detection or permanent inactivity tasks. First tests were conducted only with small transmitters and the use of cabled receivers. Figure 2 shows pocket transmitter and complete *KT200LinkMe* device, high importance has been given to portability and low consumption of both devices. The main task has been to determine the suitable distance for the receivers that would allow to grab a signal from any position amongst the to-be-monitored wing from at least one but no more than two (or three depending from the intrinsic spatial configuration) receivers.

Acceptable results were obtained using five receivers on a 110 m corridor and one extra receiver about 20 m out of the wing on the access path to the corridor. The small transmitter that has to be given to patients are set up to broadcast their code (each transmitter sends a few bytes univocal code, so that exact identification is allowed) each 7-8 seconds. After some tests, this transmission frequency has been adopted as a good compromise between: the distance walked or covered on a wheelchair between two consecutive transmissions from a patient, battery endurance (expected to be about 1.5 year), amount of data generated with related problems of traffic and collision avoidance of radio packets. During test sessions many problems arose and have, some partially, some other completely, been solved. Some challenges still have to be faced and are mainly related to the identification of a typical user's behaviour and some adaptive algorithms that must generate an alarm when there's the concrete clue that the patient left or is about to leave monitored zones. This because radio signal can be lost or obstructed as well as not being received at all, due to the reason that the patient has left monitored area. Different solution are under evaluation:

- to use a detector on the corridor accesses, if the patient walks through them an alarm signal is generated, a radio transmitter/receiver are mainly used (obviously only for data analysis about the patient's behaviour);
- to install further receivers on park paths and in correspondence of other accesses out of the monitored corridors. If these additional receivers detect the signal coming from patient's transmitter, the alarm signal is generated: grabbing a signal far from where the patient is expected to be, will cause an alarm generation;
- to develop some smart detection software that analyzes the path followed by the patient and alerts when the direction is towards corridor's access points. Alarm message is generated when, after potentially escape paths are walked, no signal from the transmitter is detected for some seconds.

[1] In references web-sites with technical features of these devices are reported.

Positioning on the op-centre program screen is made drawing an icon with patient's name in correspondence of the map position of the receiver that detected the radio signal coming from the pocket transmitter. The latest receiver that grabbed the signal represents the indicative patient's position. If patient is in an intermediate position and the polling-style request made to the receivers makes the patient's position bounce from one receiver to another, a filter-like algorithm is applied: the monitored subject is positioned in an intermediate location and the data that will be stored about patient's activity will not reflect the above indicated bouncing.

Figure 2: a: complete device *KT200LinkMe*; b: a pocket radio transmitter *KFT-BestIdea*.

3.1 Testing of the positioning device *KFT200LinkMe*

The following steps have been performed to test the complete *KT200LinkMe* device. This object can be used in three main configurations, described in the following.

3.1.1 Configuration 1

As with the small transmitter configuration, this device scans the air to detect signal coming from cabled transceivers. If it recognizes of being in a radio monitored zone, it sends radio packets containing its personal code and possibly a frame with the most recent GPS coordinates detected and patient clinical monitored data (e.g body temperature, heartbeat and similar, obtained from external sensors and properly coded). This allows the patient to be constantly connected and monitored by the op-centre, without the need of GSM communication.

3.1.2 Configuration 2

If the above described situation is not available: for example the transmitters that the device detects are not cabled with the op-centre (dual solution) or if there is no transmitter's signal detection at all, but the GPS signal is available (this probably means patient is in unmonitored zone either outdoor or indoor) the communication is made with GSM, upon hospital personnel's request The communication could be set-up as a data continue communication: every few seconds the position on the screen is updated and the patient could be easily located. It's also possible to contact with a voice call the patient, in order to verify his/her health conditions, if no movements are detected for a long time or if panic button is pressed by the patient.

3.1.3 Configuration 3

Patient's position is monitored by periodical SMS sent from the op-centre to the device. The device turns on the GPS module (kept off once the fix is obtained and no movement upon a programmed threshold is detected, this is very effective to save batteries)and, once a new point is fixed, the device answers with a SMS containing information about its current location.

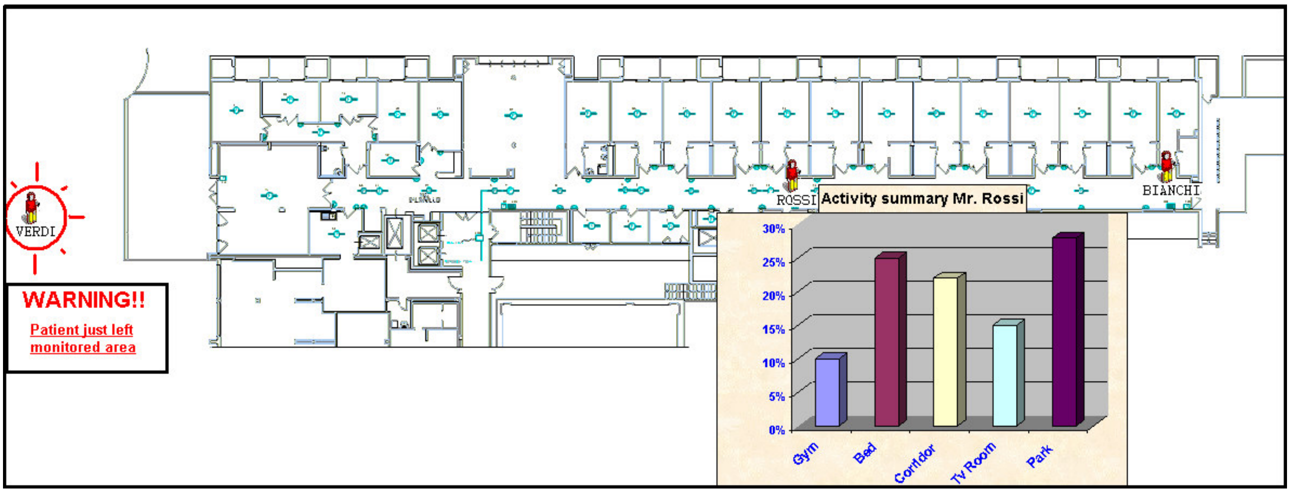

Figure3: Three monitored patients are in the corridor area, while on monitor are shown Mr. Rossi's stats, an alarm is issued due to the fact Mr. Verdi left allowed zone. This can be obtained because an external radio receiver gets Mr. Verdi beacon's transmission or because GPS is turned on and fixes a point far from allowed zone.

3.1.4 The testing area

Figure 3 shows a screenshot from the op-centre software where 3 patients are monitored, an alarm shows a patient left monitored corridor, while hospital personnel was retrieving statistics about where another patient spent his/her day.

The *KT200LinkMe* has been initially configured with georeferenced target upon the hospital area, if GPS signal (upon suitable tolerances) exits from this pre-programmed target, indicatively covering hospital and park area and enters any zone surrounding hospital park, an SMS alarm is sent to the ILG connected to the op-centre, indicating the latest position and the fact that the patient has left allowed area. In addition to this, the device is configured to save its location (retrieved with above described methods GPS or radio transmitters) every few minutes. Every evening, when the device's battery is recharged, data about patient's movements are transferred to the op-centre for being processed.

Some assumptions have been made in order to let the device switch to radio or GPS for localisation: priority to the localisation is given to radio signal, if radio signal is detected, the positioning is made basing on the code received from the radio transmitter. This choice allows to reduce the intrinsic positioning tolerance derived from low cost, low consumption GPS receivers, the error in positioning with this method is indicatively the communication range of the radio transmitter (about $\pm 15 \div 20$ m). When no radio signal is detected and there's an incoming position request, the GPS is turned on, when the fix is available, position indication is sent back to op-centre by SMS or dedicated data call.

4. FINAL CONSIDERATIONS AND FUTURE WORK

Project took over on July 2005 as part of a bigger partnership between Politecnico di Milano, some medical local institution and companies in the Province of Lecco (Lombardia, Italy). The quest was really interesting and the spectrum extremely wide. Many different problems that needed to be solved were on the table. The beginning idea of an integrated GPS/Inertial unit with storage capacity that would solve the whole matter is definitely not to be abandoned, due to its potential high impact on the solution for a wide range of questions. It's anyway actually inapplicable at sustainable costs: it's not yet possible to perform such tasks onboard on a portable device that potentially has no communication mean with a more powerful number-crunching machine. Related power consumption, hardware complexity and evaluating capacity to be used for such challenge are still not up to be reached nowadays altogether in one pocket size stand-alone device. More and more resources need to be employed and a much wider group of inter-disciplinary human resources must be involved to solve such a problem once technology won't be a gap anymore. From medical advisors to physician, physiotherapists, IT engineers and also human behavioural experts will have to gather to find the best solution for this problem. The developed project tried to cover the widest area possible of the problem with solutions that are actually technologically pursuable. Even though the ideal solution to the single problem could have been faced in a different way, sometimes also with cheaper hardware or less complex software, the workout of the project tried to be a good compromise between all aspects of the matter and a good example of resources optimization. We followed quite a different path from standard research method: instead of going straight towards the problem core and trying to find a solution regardless of costs and applicability, thanks also to the strong cooperation with an industrial company, the working group always kept an eye on fulfilling the problem requests and maintaining sustainable development costs.

Depending on the aspects that in a specific occasion have priority (patient monitoring, physical activity data collection, indoor/outdoor positioning, path reconstruction, alarm generation and so on) different solutions have been worked out.

Testing sessions are still in progress to try to further refine all the players requirements, commitments included:

- is it thinkable that a patient will wear and use such a device? Which problems (technical and behavioural) could occur if its application will not be completely "transparent" to final user?
- Which data do medical institutions want to gather? How often do data have to be collected? Which indicators are really useful?
- Will there be enough human resources available to evaluate the gathered data and find aggregation criteria, behavioural statistics and other indicators that will lead to a useful set of hints for prosthesis developer or other studies to improve disabled patients way of life?

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