Assistance to the maintenance in residence of the handicapped or old people

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ABSTRACT. The maintenance at home of handicapped or old people poses two major problems: the safety of the persons and their autonomy. To answer them, the project combines two approaches: remote monitoring for safety and functional substitution for autonomy. A system of remote monitoring makes it possible to the person to remain at home while taking advantage of a medical supervision remotely and thus of a good reactivity in the event of emergency. Functional substitution is ensured by a robotized assistant able to manipulate usual objects. The assistant contributes to the integration of a person with reduced mobility in a daily living environment. Originality of the project lies in the combination of a remote monitoring system with robotics. The mobility of the robot can ensures a more robust detection of alarming situation, a more robust transmission of alarms and ambulatory data of the patient, a decision-making help after alarm and above all, an audiovisual contact in the event of alarming situation between patient and a distant medical operator. The paper presents the state of works of the project in remote monitoring and functional substitution for object manipulation and shows the interest of the cooperation of both services.

RESUME. Le maintien à domicile de personnes handicapées et/ou âgées pose deux problèmes majeurs : la sécurité des personnes et leur autonomie. Pour y répondre, le projet combine deux approches : la télévigilance, pour la sécurité et la suppléance fonctionnelle pour l'autonomie. Un système de télévigilance doit donc permettre aux personnes nécessitant une surveillance médicale de pouvoir rester chez elles et de pouvoir, si nécessaire, être "médicalisées" à distance de manière plus réactive en cas d'urgence. En ce qui concerne la suppléance fonctionnelle, l'assistant de saisie et de manipulation d'objets usuels contribue à l'intégration d'une personne à mobilité réduite dans un environnement de tous les jours, c'est-à-dire sans équipement particulier. L'originalité du projet réside dans la combinaison d'un système intégré de télévigilance avec des moyens robotiques. Les capacités de mobilité du robot assurent selon les phases ou les besoins de l'utilisateur : la détection plus robuste des situations alarmantes, la transmission plus robuste d'alarmes et de données patient entre le terminal de télévigilance sans fil et la station domestique fixe, une aide à la prise de décision après alarme destinée à l'opérateur distant de télésurveillance, la suppléance fonctionnelle pour la saisie et la manipulation d'objets.

KEY WORDS: Remote monitoring, assistive robotics, functional substitution, Human machine co-operation, physiological data, actimetry, control mode.

MOTS-CLES: Télévigilance, robotique d'assistance, coopération homme-machine, donnée physiologique, activité.

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1. Introduction

The maintenance at home of the disabled and/or old people takes an increasing importance as an alternative to hospitalisation or placement in specialised institutes. The number of persons with reduced mobility is presently increasing, specially because of the lengthening of the life expectancy and also because of the saving of persons badly injured in accidents. INSEE study of October 2000 indicates that about 2.3 millions of persons in France, living at home, receive an allocation or another income because of their handicap, their advanced age or any health problem. More than 5 millions of persons have a regular help to accomplish certain daily living tasks and need a constant monitoring. Two times on three the help is given, by the persons' family. Difficulties are of different intensity depending on the nature, the origin and the gravity of the injuries. Women suffer more of motor deficiencies and men suffer more of sensorial deficiencies. Age is a worsening factor: motor deficiencies affect two third of person of more than ninety years old. More than 650 000 disabled people live in specialised institutes. According to INSEE, these persons suffer at different deficiency levels:

- motor (13.4%)
- sensorial (11.4%)
- organic, for example respiratory or cardiovascular (9.8%)
- intellectual of mental (6.6%)

More precisely, about 1% of the population suffer of important motor deficiencies (quadriplegia, paraplegia, hemiplegia).

The maintenance at home poses two major problems: the safety of the people and their autonomy. They are generally solved by the constant presence of a third person. The project aims at proposing a solution to decrease this presence, but only in its utility aspect. The purpose of it is not to remove any human presence around the disabled and/or old person. Decreasing this presence is a clearly expressed wish, in a quite comprehensible will of intimacy. To make possible maintenance at home, the project is interested in two aspects: remote monitoring for safety and functional substitution for autonomy. We understand by functional substitution the assistance for usual tasks of manipulation thanks to a semi-autonomous mobile arm manipulator, remote controlled by the disabled and/or old person. In the literature no project approached the problems of the maintenance in residence by combining remote monitoring and robotics. The literature survey will thus approach separately remote monitoring for security and functional substitution for autonomy. In the context of remote monitoring, we can cite pilot experiences done in Israel, Norway, Canada, Germany like Philips Heartcare Centre (Philips) and France : experiments of France Telecom research and development for dialysed patients, old persons, Biotel system exploited by SAMU-92 (Baer *et al.*, 2000), fall detection developed by the team of Grenoble (Noury *et al.*, 2003) They offer very interesting experimentation fields, which have permitted to obtain technical solutions for

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remote monitoring. However many scientific and technical points are still to improve for example:

- Reduction of the rate of false alarm to avoid useless interventions. A solution is based on a multimodal fusion of vital physiological parameters such heart rate measured on the patient, actimetry which measures patient activity and patient localization inside the residence.
- Reliable and protected transmission of physiological data and actimetry of the patient towards the residence station.

In connection with lack of autonomy, many handicapped people (quadriplegia, muscular dystrophy, confined to bed people...) have great difficulties, even an disability to seize current objects (glass, deliver, quill, etc.). Robotics proposed three configurations for functional substitution: a robotized arm fixed on a desk like AFMaster (Busnel *et al.*, 2001), a robotized arm fixed on an armchair Manus Kwee *et al.*, 2001), (Evers *et al.*, 2001) or a robotized mobile arm MOVAID (Dario *et al.*, 1999), HTSC project of Amiens (Chaumont *et al.*, 2005), ARPH (Hoppenot *et al.*, 2002). Up to now, one can note that only Manus arm fixed on an armchair remains marketed. This configuration presents nevertheless two important limits of use when the person is confined to bed or that she wears a collar and wants to collect an object on the ground. An arm manipulator embarked on a mobile basis offers a response in these two situations. Up to now projects carried out in this field did not succeed. The field of research remains open. It is necessary in particular to improve the coordinated control of the mobile arm and the interaction between user and robot.

The project can be divided into three steps: remote monitoring, functional substitution and combination of these approaches in order to propose a global response for the maintenance in residence. First section describes the whole of the system with its functionalities and its devices. The end of the section underlines the contributions of the combination of the two approaches, remote monitoring and functional substitution. Second section provides the current results obtained in remote monitoring and the following section the results in functional substitution. The last section describes works in progress.

2. Principle and originality

In order to avoid any ambiguity, we define the following terms which will be used in the paper.
Patient device: Ambulatory device placed on the person for acquiring physiological and actimetry data
Residence station: System of treatment of data provided by patient device and then of transmission from the patient residence to the remote monitoring centre
Remote monitoring centre: Distant place for decision making by medical specialists typically SAMU in France.
Mobile arm: Mobile robotized arm

Control station: Station in residence which allows the control of mobile arm by a human user; in our case a disabled person.

2.1. Remote monitoring

The person living at home can benefit from two services. First remote monitoring is presented in figure 1. The principle is to measure certain physiological data and the activity of the person. According to the value of these measurements, an alarm is transmitted to the *Remote monitoring centre* which makes or not the decision to intervene.

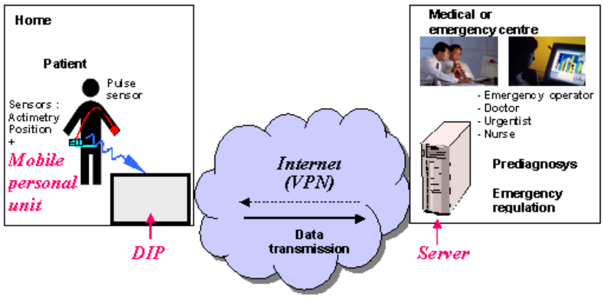

Figure 1. Principle of remote monitoring of patients in residence

The system is generally composed of two fundamental elements:
Patient device placed on the patient permanently recording his physiological data -mainly heart rate-, his actimetry eventually supplemented if the health of the patient requires it by sensors for the recording of an electrocardiogram (ECG) or an uninterrupted ECG (Holter) and by a sensor of oxygen saturation rate.
Residence station which receives signals from *patient device*, analyses data in order to generate an alarm after identification of an emergency. The alarm is transmitted to *Remote monitoring centre* for decision making.

2.2. Functional substitution

The second service is functional substitution for usual object manipulation. It concerns motor disabled people unable to move in the residence. The principle is illustrated in figure 2. The assistant is composed of :

- a mobile base with two drive wheels
- a 6 dof manipulator arm, MANUS, carried by the mobile base (figure 2)
- a pan-tilt camera. The camera plays different parts: video feedback for user, perception for automatic control mode and remote monitoring
- a *Control station* for the control of the mobile arm by an user. The station is composed of a man-machine interface and a wifi transmission link to communicate with the mobile arm (figure 3).

Figure 2. Principle of the functional substitution

When disabled person needs an object, mobile arm is sent to seek the object in another part of the residence. Thanks to its own capacities of mobility, perception and seizure, it is able to bring back this object.

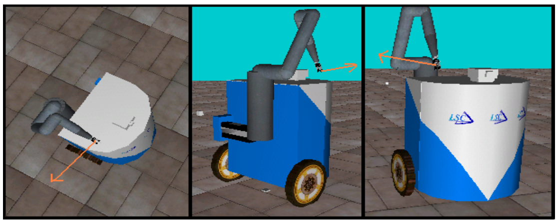

Figure 3. Views of mobile arm

In the facts this task is carried out by a human machine co-operation. The robot must be able to move while avoiding obstacles and locating. It is remote controlled by the user thanks to a control station which is typically a personal computer. As seen later, various control modes are at the disposal of the user.

2.3. Co-operation between Remote monitoring and functional substitution

The original idea of the project is to combine remote monitoring and robotics to supplement or improve the services of maintenance in residence. Indeed the capacities of mobility of the robot allow according to needs: to confirm alarm, to remotely ensure an audiovisual contact in the event of alarming situation and to allow functional substitution for the seizure and the handling of objects. To our knowledge, such an approach of co-operation between an ambulatory system of remote monitoring and a mobile robot equipped with means of perception has never been proposed. The modular concept makes it possible to adapt the system to the real needs of the person: remote monitoring alone, functional substitution alone, or both in co-operation which can be illustrated by the following scenario. An alarm is set on by the residence station. The distant operator of remote monitoring centre is alerted. He tries to get in contact with the person by usual means of telecommunication in order to ensure himself of the validity of alarm. He does not obtain any response. Consequently, he orders the mobile robot to seek the person in her residence and then to establish an audiovisual contact with her. It is not a false alarm. The distant medical team specifies the diagnosis using the remote monitoring data and the audiovisual data -image and sound- provided by the robot, defines the means of necessary intervention and starts the intervention. While waiting for the arrival of assistance, audiovisual contact is maintained with the person. This scenario illustrates the contribution of robotics to the service of remote monitoring. Reciprocally the measurements acquired by the system of remote monitoring can be used to adjust functional substitution constantly with the needs of the person. Indeed, as seen before the user has at his disposal different control modes for the control of the mobile manipulator arm. The person makes the decision of the better mode to be used. However it would be interesting of proposing a control mode related to the state of the person. The sensors of the remote monitoring system can be used by the functional substitution system for decision making.

3. Remote monitoring

The INTERMEDIA team takes part of the “département Electronique et Physique” belonging to the GET/INT Institute which has both educational (Engineer schools) and research missions. Their technical works and platform realisations were performed thanks to the RNTS project TelePat1 partnership by taking into account medical and user-centred requirements. In addition the GET/INT team, through one task of the TelePat project, developed more deeply its research on the remote actimetrics/vital signs watch (Télévigilance) (Baldinger *et al.*, 2004), and on "telecardiology" part (Andreao *et al.*, 2004), (Boudy *et al.*, 2006) which can be seen as a subset of a televigilance system, namely for cardiac persons: an ambulatory cardiac monitoring system must be able to produce an automatic alarm based on an automatic electrocardiograms (ECG) signals segmentation and identification of pathological ECG waveforms (arrhythmias, pre-infarctus or vascular accidents signs).

The following section describes the state of works developed by Intermédia-INT laboratory. As said above, the system is generally composed of two fundamental elements:

- *Patient device* placed on the patient permanently recording his/her physiological data
- *Residence station* which receives signals from *patient devic*e, analyses data in order to generate an alarm after identification of an emergency. The alarm is transmitted to *Remote monitoring centre* for decision making.

[1] TelePat: French acronym of "Remote monitoring for Patients in Residence", this project is funded by the French RNTS program and acts from Nov 2003 till July 2006. The partnership is composed by all organisations mentioned in this paper authorship. TelePat extends works performed in the MEDIVILLE project (French ACI program).

3.1. Patient and home infrastructure

Most of telecare application for elderly patient at home target fall detection and require a reliable alarm system able to warn a telesurveillance or urgency centre by avoiding false detection : indeed most of urgency cases for elderly people are falls events and several approaches are proposed based on position and inclination measurements and accelerometers sensors such as proposed by (Noury *et al.*, 2003) in showing already satisfactory fall detection results (about 80% good detection, recently reaching 95%). Based on the approach (patients' body position and fall's impact smart sensor) developed with the TELEPAT device, initially based on the TELEPAT system, intends to propose an original and simple fusion scheme by combining the patient's position to an agitation measurement, to and fall impact detection and to the heart rate frequency (pulse measurement) : indeed the pulse measurement is generally not associated to fall detection schemes as considered as too much unreliable measurement. Namely this was a novel contribution from TELEPAT (early targeted in MEDIVILLE Project) to add the pulse measurement to other actimetry parameters in order to provide a real-time tendency of the patient's health status : the only condition was that we could make pulse signal acquisition more robust by reducing measurement noise. This was one of the challenging work targeted by MEDIVILLE and finalized at the beginning of TELEPAT.

One of the most important problems for the devices worn by the patient, and namely for the ECG signal measurement, is the disturbances generated by the movements (myoelectric and displacement electrodes noises) or the capture of external signal sources interferences (electromagnetic, power line, etc.). On the other side, trying to eliminate these disturbances often means sensors more intrusive for the patient. Based on preliminary investigations on existing biomedical research and experience feedback from healthcare professionals, the TELEPAT project has specified the portable device according to a trade-off between a minimal invasiveness and robustness to any kind of interferences, hence by targeting a simple and low-cost system. The portable sensors, fixed to the patient, are measuring over a certain time period his body orientation (compared to vertical and horizontal references), activity degree (also denoted actimetry), his heart rate (or pulse rate) and are detecting fall of the patient ; an ECG measurement can be performed separately, with a specific measuring device directly manipulated by the patient under the distant control of a physician. The data generated by the different sensors are transmitted, via an electronic signal conditioner for the pulse rate, to a microcontroller based computing unit. Signals conditioner and computing unit are embedded in a case (mobile personal unit) fixed on the patient's waist.

The personal computing unit realizes signals numerical and statistical treatments to reduce effects of ambient perturbation evoked previously.

The personal computing unit or Patient device - also denominated wearable terminal - (Figures 1 & 4) includes an acquisition chain of the various physiological signals, their possible pre-processing in order to eliminate the power-line interference signal (50 Hz) and the various measurement noises, such as ones generated by frictions or displacements of the sensors laid out on the patient's body. The latter type of noise is generally a factor limiting the use of such systems in ambulatory mode because the patient is often moving, even if slightly. In our system, the noise problem was solved in the acquisition stage of the portable device (Baldinger *et al.,* 2004), of the pulse, by applying a digital noise subtraction filter to the different sensors signals, movements, attitude and namely the pulse signal (heart rate) where the performances of signal acquisition could be very appreciably improved when the patient performs movements.

Namely an important research work was devoted to signal processing improvement within the micro-controller to make the pulse signal acquisition more robust to patient's movements: an original noise reduction algorithm implemented in the micro-controllers has allowed to lower measurement standard deviation below the 10% required threshold, even reaching a 5% bound.

It was developed by (Baldinger *et al.,* 2004) and achieved to reduce the variations of pulse measurement lower than 10%, even 5%, which remains in conformity with the recommendations of the Health Professionals.

Figure 4. Real-time and experimental wearable personal terminal for televigilance

The design of sensors and embedded treatments has led to the realization of a remote wearable monitoring terminal, equipped with actimetry and physiological sensors, indicating the attitude of the patient (vertical/horizontal positions, activity) and his heart rate (pulse measurement); these sensors specific to the recorded physical data type are, either integrated in the terminal (actimetry), or externally fixed for instance in the case of the sensor of pulse placed on the ear or at the wrist according to the blood stream properties of the considered patient (comparative studies carried out within the laboratory). Figure 4 shows a Real-time and experimental wearable personal terminal for televigilance (Baldinger *et al.,* 2004), equipped of sensors for heart rate (on ear) and actimetry (inside), with the in-door reception base-station: various physiological values on the blue display after fusion processing performed within the base-station.

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Data generated from the different sensors are transmitted, via an electronic signal conditioner, to a micro-controller based computing unit, embedded in the mobile terminal fixed on the patient's waist. Additional accelerometry sensors to measure the fall impact are currently under finalization to refine, to even carry out a more secure identification of any fall.

Evaluation of sensors based on unitary tests

The objectives were to validate each sensor independently, starting from real or simulated states of reference of the patient. Pertinence and the reproducibility of each information must be controlled as well on the IDP level as on the medical centre control terminal one (Lacombe *et al.*, 2005). The states of reference must be defined in a precise way to be able to compare statistical series of data. Taxonomy is proposed in table below to classify the different reference states, according to the type of data delivered by every sensor.

Position sensor	
Main situation	**Alternative situations**
Upright patient	No motion
	Medium activity (walk)
Lengthened patient	Left side position
	Right side position
	Ventral position
	Dorsal position
Sitting in an armchair	
Pulse sensor	
Main situation	**Alternative situations**
Pulse > 100	High activity (run or exercise bike)
	Normal activity (walk)
	Null activity (Lengthened)
100 > Pulse > 40	High activity (run or exercise bike)
	Normal activity (walk)
	Null activity (Lengthened)
0 > Pulse > 40	Sensor not worn by the patient
	Pulse electrically generated
Actimetry sensor	
Main situation	**Alternative situations**
High activity (run or exercise bike)	
Normal activity (walk)	
Reduced activity	Sitting in an armchair
	Lengthened (sleeping) patient
Null activity (Mobile personal unit not worn by the patient)	

Table 1. Reference situations taxonomy for this evaluation.

Results obtained with the unitary sensor test applied to position and motion sensors were satisfactory as providing an accurate response to the attitude (lied down or standing up) and activity (low, medium or high motion) of the patient. Pulse sensor was previously and separately evaluated.

Because of the difficulties ecountered during these tests, it was not easy to cluster motion values (spanning from 0 to 15), therefore we rather introduced the idea of a percentage motion ratio by trying to zoom difference between no absolute motion and low motion.

The additional accelerometry sensors to measure the "fall impact" under finalization will be next evaluated based on this methodology completed by specific reference fall scenarios currently to be studied.

In-door Basestation

The wearable patient's unit forms the data frames that will be sent periodically, threw a local radio network channel, to the In-door Basestation, also denominated as "Domestic Internet Platform" (DIP), which is a fixed specific computing unit placed in the patient's home : this was developed by the ESIEE team (Lacombe et al, 2005) in close relationship with GET/INT in all their past and currently active Televigilance projects. The sent frames also include the state signal of an emergency call button, that can be manually operated by the patient. The DIP is in charge of prediction information and alarms generation, starting from rules worked out by the fusion of the different data. All indications and alarms are transmitted to a server, the MEDICAL Centre Server, placed in the emergency or surveillance centre, via an Internet Virtual Private Network (VPN) channel.

Still in TelePat project, in order to reinforce the secure detection of patient's fall event, It is also planned to combine measures coming from the patient terminal with those of the system GARDIEN (Steenkeste *et al.,* 1999) allowing the patient's localization by Infra-red sensors fixed on specific places of the rooms (walls and ceiling).

This data fusion is currently under development and is located within the in-door reception base-station. The "Residence station" – also called local base-station - carries out for instance one or more filtering process on received signals to improve their signal-to-noise ratio and their quality, to estimate the patient's health tendencies (slow or abrupt variations of its heart rate, to prevent risks of bradycardia…). It carries out the fusion of the various physiological and actimetric values in order to calculate an alarm or emergency index, then retransmitted through a secure VPN link to the remote server of the medical control station.

The data retransmission from the local base-station towards the TelePat centralized server –also called *Remote monitoring centre*- was implemented on an IP network offered by the PERCEVALE project managed by INT. The TelePat remote server connection to the PERCEVALE network authorizes an open access on the outside world (no firewalls), which will make possible in the long term an access from other domestic-patient stations outside to INT (e.g. to simulate a televigilance service deployment with several patient's in-door base-station to manage by a medical centre). In that context it is crucial to guarantee a minimal QoS between in-door base-stations and the remote medical supervision centre. (Serra *et al.*, 2005) proposed, for large scale deployment of televigilance servers grid, an innovative model of intelligent QoS management, the WS-DSAC concept (Web-Servers Diff. Serv. Admission Control): WS-DSAC computes in real-time the load sharing between several servers in grid to allocate optimal resources in case of high and simultaneous emergencies load (Serra *et al.*, 2005).

3.2. Medical Centre server and database

According to the procedures defined by the medical team, the system allows, thanks to the remote server facilities, a data communication and data history analysis in a quite flexible way for the local team or for the physicist connected as client to the central server. The system deals with three different databases: the main database, the medication database and the pharmacological models database (Lacombe *et al.*, 2005).

Main Database

The main database is composed of three main parts : the directory, the time sequence data for patients, the medical imaging data. The directory is the most important part of this database. From this database, the qualification of the user is obtained (administrator, practitioner or patient). The administrator is the only user that may generate an entry in this part of the database. He also defines the access rights of each user.

The directory of the practitioner contains his coordinates, accessibility, password and the list of patient data that he may access. The directory of the patient contains his coordinates and the entries to his historical data. It also contains the coordinates of the centres that are contacted in case of need with their order.

The practitioner may enter information in a patient record he can access. The Time Sequence Database contains the entries for each patient to the various data (signals) that are monitored. This allows the practitioner to obtain the historical evolution of each signal. This database also contains the necessary tools for visualising the patient’s data and their comparison to reference data.

It is directly fed with information from the monitoring system and the consistencies of the records are regularly checked through the comparison with the data stored at the patient system. This verification process requires a regular synchronisation of the patient system clock with the central system one.

The information stored for each patient (data history) is fixed by the practitioner. The access to the archived data concerning a specific patient can be made only at the request of its attending practitionar. Furthermore, anonymous standard data information are used to build symptoms or pathologies models available to any practitioner. The patient is kept informed of this process and of the storage and availability of his personal data. He may ask, at any moment, to leave the information system.

The imaging database consists of the totality of imaging data concerning the patients and is detailed in (Lacombe *et al.*, 2005). The storage is done in standard medical images format (standard DICOM) and includes, in the same manner as the previous database, two parts: an anonymous reference database and patients’ database available only to the practitioner.

As in the previous case, data from the patients' database may be included in the reference database in an anonymous manner.
The tools associated to this database include the means for indexing and searching images according to the nature of their contents. To simplify the work of the practitioner, he may ask for images "similar" to that of the patient he is concerned with. This Main Database is implemented on various disks and servers in order to accelerates the simultaneous access.

4. Functional substitution

The mobile arms make it possible to extend the zone of action of the operator and can be used in an not structured environment. The Manus arm, developed in Holland, is marketed since ten years. It is conceived to be embarked on an electric wheelchair. It is an arm with 6 degrees of freedom with a grip at its end which can seize an object of 1,5 kg. It is controlled thanks to a 16 key keyboard. This configuration showed its effectiveness since 150 Manus arms are currently in service in the Netherlands. In France, one counts only about thirty Manus, primarily thanks to the action of the AFM. The absence of an institute specialized in the provision and the follow-up of this aid and the fact that the majority of the technical innovating assistances are not refunded in France explain this difference.
Two limits appear for this type of system. For confined to bed people, the aid becomes inoperative. Moreover, it is sometimes impossible to collect an object on the ground, for example when the person carries a collar preventing her from seeing on the level of the ground right beside the armchair. A solution consists in embarking a Manus arm on a mobile structure. This configuration is more flexible than the two preceding ones. It is also more delicate to work out. Two situations are possible. Either the robot is in the field of vision of the operator and the control is carried out with a direct visual feedback or the robot is out of the visual field of the operator who must remote control it. Until now the research projects based on this configuration did not reach a phase of pre-industrialization. The principal problem underlined by the authors is the difficulty in controlling a complex system by a handicapped user.

4.1. Human-Machine Co-operation

IBISC is developing a functional substitution system being inspired by the third configuration presented above: a manipulator arm embarked on a mobile base called ARPH (Robotics Assistance for Handicapped persons). From the beginning of the project, in 1994, the AFM (French Association against Myopathy) was actively involved of our specification and design. In the following we present the state of ARPH project. Our works articulate around two complementary axes. The first one, centred on the user, aims at supplying him an assistance according to his wills and his residual capacities. It deals with the cooperation between the user and the machine to reach the wished objectives. Two imperatives are become obvious. First of all, leave the person free of her choices at all the levels by an appropriation rather than by imposing operating modes then, mitigate the limits of the technical assistant thanks to the human intervention. To answer it, we developed three types of modes of command. The first one is the manual mode. It gives to the user the control of all the degrees of freedom of the system. Its main drawback is its difficulty of use for the person. In the second mode, the system executes automatically the mission wanted by the operator. The first defect of this mode is to forbid the operator to act by himself while it is often an expressed wish. The second drawback results from the difficulty of proposing a totally autonomous system without equipping the environment and by staying in acceptable costs. We thus opted for the definition of the third type of modes palliating the drawbacks above. It consists in sharing the control of the mission between the operator and the system. We called them shared modes. Some are proposed to the user. A first shared mode consists in assisting the operator for the avoiding of the obstacles being on the road followed by the robot. The operator gives the direction to follow, the robot takes care to avoid the obstacles. A second shared mode, called camera mode, is based on the control of the movement of the mobile base. A camera, directional in site and in azimuth, is embarked. Here, the operator pilots the orientation of the camera and the robot moves in the direction. Another version of this mode is possible by using the function of follow-up included in the camera. it consists in following automatic movement of an object by keeping it constantly in the centre of the image. Once the object chosen by the operator, the camera follows it and the mobile base moves in its direction. Besides modes of command proposed to the operator, the man-machine cooperation man is based on a good understanding by the operator of how machine operates. In robotics, several works use the model of human operator divided in three levels of behaviour (based on the skill and knowledge, governed by rules) proposed by (Rasmussen 1983). By trying to match the functioning of the machine on this model we approached the question under another angle by referring to the works of Piaget on the adaptation of a child to his environment (Piaget, 1936) According to Piaget, the intelligence is above all adaptation which can be decomposed into two additional processes. The first one is assimilation which consists of the generalization of pre-existent schemas. Concretely, by their nearness of appearance or situation, new objects can be likened with pre-existent schemes and to see themselves attributing meanings which contribute furthermore to an extension of the behavioural knowledge base. The second, the accommodation, consists of the differentiation of the pre-existent schemes and requires a more important cognitive investment. In the project ARPH, we studied the means to allow the user to adapt itself to a new tool by assimilation rather than accomodation process in order to limit the workload of the user (Rybarczyk *et al.,* 2002). The studies on the morphology of the system showed that by supporting an anthropomorphic placement of the visual frame by report to the end effector frame (position of the feedback camera with regard to the manipulator arm), user develops an adaptation rather from assimilation type. Other studies concerning morpho-functional aspect, for example the visuo-motor anticipation mechanisms showed that by reproducing the human behaviour, here also the user adaptation is done rather by assimilation.

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4.2. Autonomy of the mobile arm

A cooperation can settle down only between two entities (here human operator and mobile arm) with autonomous abilities. So, the second axis of our works concerns the autonomy of the mobile arm. Seizure of an object, remotely, to manipulate it, distinguishes two phases: approach and seizure itself. The approach is carried out mainly by the mobile base which carries the arm. If the phase is automatic, it is necessary to define at first the path to be followed, it is planning, then to follow the path while correcting locally if necessary, it is navigation. The latter uses the localization to check that the followed way is that envisaged. Planning establishes a graph of visibility starting from a priori knowledge of the environment and chooses the best trajectory, in the sense of a function of cost to be defined, thanks to the algorithm A^*.

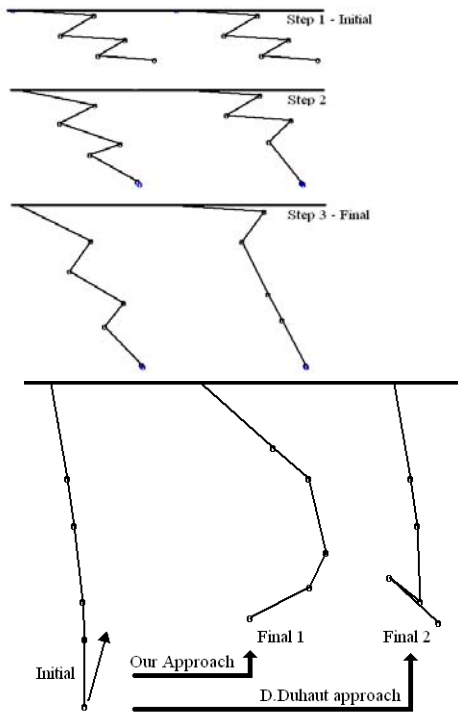
Navigation is based on the fusion of two behaviours: follow-up of trajectory and avoidance of the obstacles. This second behaviour is possible thanks to measurements of ultrasound sensors. The fusion is done by a fuzzy controller.

Lastly, the localization is essential for an automatic displacement of a point to another. We use a hybrid metric localization. Dead reckoning provides a robot positioning continuously but with a increasing error. So, regularly a method based on video data corrects robot position by reinitialising dead reckoning (AitAider *et al.,* 2005). Another work deals with symbolic localization.

For the seizure phase itself, the problem is more complex. The movement of the end effector of the manipulator arm depends on commands sent to the arm and on those sent to the mobile base. This redundancy of the degrees of freedom allows to impose constraints on the way of realizing a task. We are interested in the concept of manipulability, introduced by (Yoshikawa 1985) and developed by (Bayle *et al.,* 2003). This concept allows to hold the remote arm far from its singular positions and so to ensure it sufficient ability for manoeuvre all the time (Nait Chabane06 *et al.*, 2006).

Another direction based on multi-agent approach is studied. The main advantage of these kinds of method is that they do not need inverse geometric model of the arm. We can find few approaches (Duhaut, 1999) (Duhaut, 1993), which describe how to reach a Cartesian position without using mathematic inverse geometric model of an arm. This method seems to be interesting in our case. Each link is implemented like an agent. Task resolution begins with the end tool link. It tries to align itself with the goal and places its end tool on the goal by uncouple itself from previous link. Then, next link do the same with a new sub goal given previously. The main drawback of the method is that the different agents have not the same weight in the problem resolution. We propose a method in which all the joints move in parallel, all the agents having the same weight to solve the position problem. Agents' behaviors are described in (Delarue *et al*. 2006).

Figure 5.a shows the difference between two approaches. The first (on the left) uses our multi-agent algorithm. The second (on the right) is given by Dominique Duhaut (Duhaut, 1993). We respectively note them MAS and MD. Simulation presents a five joints arm manipulator on a 2D plane. The arm stretching is presented in three steps.



a b

Figure 5 : Comparison MAS and MD

We can see that during stretching, the MD approach tries to unfold members beginning by the last one. The MAS system unfolds all members in the same time. So, final configuration is more homogenous and doesn't induce any alignment and thus limits singular positions. Moreover, visual aspect is more familiar to the user and human machine co-operation is made easier. When a person wants to take an object, he does not stretch himself to the maximum, he tries to keep a homogenous posture.
Figure 5.b shows an arm folding. Again, we can see a more homogenous behaviour for the MAS approach. There is no collision between limbs.

Duhaut's method (Duhaut, 1993) does not permit to simply take into account a joint fault. We only present results with our method. Figure 6 shows system behaviour including two broken joints (dashed limb and squared joint). We mean broken joint when the motor of the arm is out of order but not the incremental encoder which gives the joint position. If the encoder is also out of order, the arm position is unknown and then it is impossible to control it.

The arm works with only 60% of its capacities. Reachable domain is delimited by two half circles. Dotted area represents the reachable space taking into account the reduced capacities. A systematic test has been realized, covering all the reachable space: 100% of the 4592 tested positions have been reached. The figure also shows three sample positions. This is possible because of the redundancy of the system.

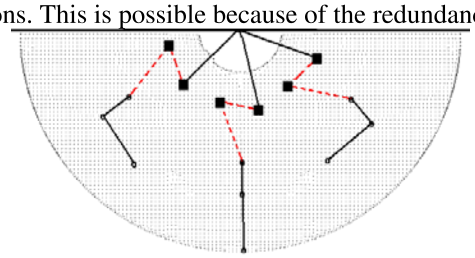


Figure 1 : two broken joints simulation with **MAS**

It is also possible to pilot the global system (mobile base & manipulator arm) using a specific agent for the mobile base. This one is more complex than the arm one, including different behaviors: forward movement, alignment with the direction of the arm, deadlock avoidance and classical reactive behavior.

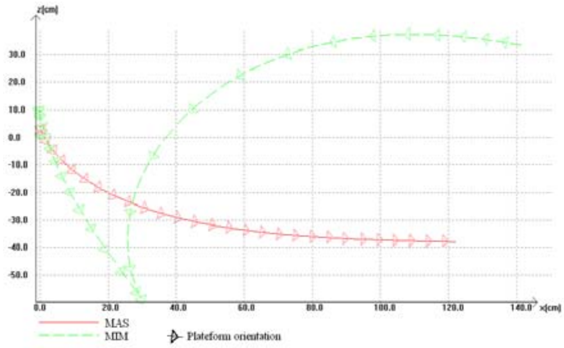


Figure 7 : MIM and **MAS** mobile base moves

Two interesting results are obtained. The first one concerns the global movement of the system. Figure 7 shows two trajectories of the mobile base using different approaches. The first one is a command minimizing Yoshokawa's manupulability of the arm (MIM). In that case, the mobile base moves backwards. In the second case, the command is calculated by our MAS algorithm which oblige the mobile base to go forward.

Another experiment shows that if one joint of the arm is broken down, the system is able to reach its goal, using the redundancy between the mobile base and the arm, which is not possible with a classical system without reconfiguring the global model.

4.3. Evaluation

ARPH system has been evaluated by disabled people in situation close to daily living. The first part of the evaluation took place in an apartment of two rooms specially fitted out. The task to be realized consisted in serving for tasting a guest. This task can be decomposed into three stages as the object to be brought back, glass, bottle, package of cake was or not in the same room as the user. Questionnaires before and after the experiment provided the data for a qualitative analysis of the usage of the robotized assistance. The second part of the evaluation proceeded in the residence of a handicapped person. The tasks were chosen by this person. The data came from questionnaires before and after experiment and from the recording of a film which made it possible to confront the person with his activity during the experiment. Several types of information were obtained concerning use, interface, ergonomics, safety, training. It should be noted that the phase of familiarisation, during which the people were free to use the robot with their own way, was particularly interesting especially concerning the need for physical exchanges with others that the robot, by its capacities of displacement and contact, makes possible. It is also interesting to note that the control of the mobile base is considered as easy by most of the persons and that the control of the arm manipulator is considered more difficult.

We have also evaluated the system by comparison between simulation and piloting the real robot for two kinds of tasks: displacement and seizure. It is interesting to see that in simulation, operators use more risky strategies than with the real system and there are more collisions in simulation than in real control. That can be explained by the consequences which are less important in simulation than with the real robot. These risky strategies permit the robot to reach the goal quicker. We have initiated another evaluation period in which we have tried to measure if competences acquired in simulation can be translated on the real system. If yes, risky strategies in simulation can permit the operator to learn how to drive the robot more rapidly without the risk of real collisions and then to transfer this skill on the real system.

5. Future works: Remote monitoring and robotics cooperation

As seen before, the co-operation of both services which are remote monitoring for safety and functional substitution for autonomy presents two major interests. In our case, a mobile manipulator ensures the functional substitution for object manipulation. More the mobility of the robot allows the capability to check if an alarm is true but also the degree of gravity of the alarm. By remote controlling the robot, the distant medical team establishes a audiovisual contact with the person at home.

The co-operation poses problems of different nature. The first one is at ethic level. It relates to the intrusion of a mobile object able to perceive and to act in the intimate environment of the person. A sociological study must establish up to what point the intrusion is bearable and which are the limits to be respected.

The other problem is the remote control of mobile robot by the distant medical operator. The usability depends on several factors: control modes, feedback and interface. Current works aims at finding the good compromise for reducing complexity without limiting the intervention capability. The only difference with the case "*the robot is out of the visual field of the operator"* is that the user is not present in residence but is located at *Remote monitoring centre*. He uses Internet for communication with the constraint that Internet is not a deterministic medium. A semi-autonomous robot mitigates this disadvantage. When the Internet offers a good quality of communication, the distant operator orders the remote robot. If there is a degradation of communication, the robot can automatically continue the task in progress.

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