Introduction :

Telemedicine is defined as the "delivery of health care and sharing of medical knowledge over a distance using telecommunication systems." The concept of telemedicine is not new. Beyond the use of the telephone, there were numerous attempts to develop telemedicine programs in the 1960s mostly based on interactive television. The early experience was conceptionally encouraging, but suffered inadequate technology. With a few notable exceptions such as the telemetry of medical data in the space program, there was very little advancement of telemedicine in the 1970s and 1980s. Interest in telemedicine exploded in the 1990s with the development of medical devices suited to capturing images and other data in digital electronic form and the development and installation of high speed, large bandwidth telecommunication systems around the world. Clinical applications of telemedicine are now found in virtually every speciality of medicine. Teleradiology is the most common application followed by Cardiology, Dermatology, Psychiatry, Emergency Medicine, *home monitoring and home health care*, Pathology and Oncology. The technological basis and the practical issues are highly variable from one clinical application to another. Techniques have been developed for the acquisition and digitization of images, image compression, image transmission and image interpretation.

Unsolved issues in telemedicine include licensure, the development of standards, reimbursement for services, patient confidentiality, data security and transmission, and telecommunications infrastructure and cost. A number of countries, states and medical boards have instituted policies and regulations to prevent physicians who are not licensed in the respective country or state to provide telemedicine services. This is a major impediment to the delivery of telemedicine services between countries and states. National and international communication networks are being created that enable the sharing of information and knowledge at a distance. Technological barriers are being overcome leaving organizational, legal, financial, and special interest issues as the major impediments to the further development of telemedicine and the realization of its benefits.

The continuing increase in the average life expectancy of men and women, coupled with a decline in the birth rate during the second half of the twentieth century will have a profound effect on the demography of many countries as they enter into the twenty-first century. Cost of care for those over 80 years is 10 times more than that for individuals aged between 16 and 64 years. At present, elderly people consume a high proportion of health-care services and in the future this proportion is likely to rise considerably. It is therefore evident that high-quality health care may in future be available universally if substantial savings can be made through the greater use of modern technology [1].

One possible solution to the problem of delivering care to an ageing population is *telecare*, which refers to the remote delivery of health and social support services in the community. Although new technologies have the potential to assist older people to live independently, there remains little convincing information about the way in which these systems affect the everyday lives of clients. It is also important that solutions to the problems of later life are not ‘technology driven’, but are based on a thorough understanding of the needs and preferences of potential clients. A major concern in supporting sick, disabled and frail people at home is the potential risks involved, such as falling on the ground and illness. An increasing effort has been made to develop systems to monitor people in their homes. These systems typically have three components :

1. A means of generating a call for help when an emergency occurs;
2. A control center, to respond to the emergency call and to initiate appropriate action;
3. Carers, who provide any necessary help.

Doughty *et al*. [2] have broadly classified this provision of telecare into three systems :

- *First-generation systems* : These are technically simple, reliable systems which are *not* intelligent, have *no* sensors and, therefore, are generally perceived to be non-intrusive. The ability of these systems to detect illness or falls lies totally on the ability of the individual to activate the alarm at the crucial moment. Hence, these systems are completely dependent on the individual’s wish. Such a system cannot be implicated in the monitoring of the demented elderly [3]. Examples are personal response systems, emergency response telephones, personal emergency telephones which can reduce anxiety among elderly or high-risk patients living alone, but the benefits of security is obtained at the expense of the individual’s confidence and self-esteem.
- *Second-generation systems* : These systems are based on sensors and continuous or continual monitoring. These sensors would then trigger alarm if an emergency condition was detected, without any intervention by the person. Such system would, therefore, possess a degree of intelligence. But due to this aspect, these systems can give rise to a large number of *false alarms*, otherwise it could result in loss of confidence in the system by both the user and the caregiver or the control center [4][5]. Examples of such systems are *movement sensors*. Unfortunately, movement sensors would be unable to distinguish between someone who has suffered a stroke and someone who has fallen asleep. Other sensors could measure room temperature

and respond if it has dropped below a certain value. But again it would be subject to error if infrared radiant heating is used instead of space heating. Other examples are smoke alarms, general security alarms to signal if an intruder has entered or the patient has left his or her house, etc. Such alarms can be considered as intrusive by the users, especially if it gives rise to too many false alarms. To achieve very low rate of false alarms and low level of intrusiveness, such systems would require much more non-invasive data about the person's characteristics and condition, which could then be interpreted much more accurately. Greatly increasing the number of sensors implies that the quantity of real-time data is greatly increased. This again raises a number of issues :

1. High levels of real-time data imply online processing, high processing power and speed at a low cost.
2. Limited bandwidth of the ordinary telephone lines may not be adequate for the control centers.
3. The user may perceive an unacceptable level of intrusiveness if personal data are transmitted.

Alarms : These are classified into three types [6] :

- *Active alarms* : Generated by the user pressing the button on the alarm unit or the button on a portable pendant. This type of alarm units are technically very simple and they form the principal component of the first-generation telecare systems.
- *Automatic alarms* : Generated by the alarm unit itself during self-testing or power failure.
- *Passive alarms* : Generated by different emergency detectors installed in the patient's house, for instance alarms due to fire, intruders, patient falls or absence in the house. This type of alarm is the mainstay for second-generation systems.

Sensor : A sensor is a device capable of capturing and transmitting the required information. In the field of telecare it can be classified according to the following types :

- *Medical sensors* : Provide data about the patient's physical condition. May be invasive or non-invasive. Ideally they should be small, lightweight and virtually invisible. The choice of devices depends on the patient's medical history and his or her needs. It has been seen that with the use of such devices at home and by regular monitoring of parameters like heart rate, blood pressure, body weight, lung function, blood glucose, etc. have reduced the number of hospitalisations and emergency room visits, but has not affected the length of stay in the hospital [7]. The different types of medical sensors are illustrated in the following table (Table 1.1) :

Sensor Type	**Functions**
ECG Electrode	Pulse rate and variability
Photoplethysmograph	Pulse rate and blood velocity, profile, blood Oxygen content
Spirometer	Respiration rate, peak flow, inhale:exhale ratio
Sphygmomanometer	Blood pressure
Thermometer	Temperature
Galvanic skin response	Sweating rate
Colorimeter	Pallor, throat inflammation
Pupilometer	Light response
Accelerometer	Fall and tremor
Polarimeter	Blood Glucose concentration
Stethoscope	Heart and breathing sounds

Table 1.1. Table showing different types of medical sensors and their uses.

- *Environmental sensors* : Monitor the space in which the person lives. Such sensors can be used to measure the room temperature, *movement* (like passive IR sensors in GARDIEN©, which is discussed later in the next chapter), presence of guests and other indicators of activity such as water and electricity consumption, touch detector, room humidity sensor, door opening sensor, Carbon dioxide sensor, smoke detector or fire-alarm, etc. [8][9][10][11][12].

Of the two sensor types, the environmental sensors would provide data relevant to *long-term* deterioration, while the medical sensors would provide information on *acute* conditions. Community occupational therapists or social workers use a scoring system such as ADL (Activities of Daily Living), IADL (Instrumental ADL) or PASE (Physical Activity Scale for the Elderly). They involve added up points awarded for the ability of a person to perform certain daily activities. A low score would be considered inconsistent with an ability to live independently. Such scoring systems are *subjective* and *time consuming* to perform. They could be replaced by an automated system consisting of simple movement detectors, door opening sensors, direct readings of water, gas and electricity consumption, metering of telephone usage etc.

In order to minimize the perceived intrusiveness of these sensors, it would be advantageous to process their outputs locally, so that only a “score” (related to well being) is transmitted to a control center by telephone. This reduces the need for large quantities of data to be transmitted and, consequently reduces the likelihood of interception and misuse. When equipped with an appropriate array of sensors, an intelligent response system is able to *compare* current data with historic data, such as from an activity chart [4], in order to detect the sort of changes that might be associated with illness or accident.

By far the greatest risk to the elderly living alone is sudden fall, whether due to stumbling, dizziness or collapse [13][14]. Research has shown that people who suffer one or more falls in a period of one year are likely to experience further falls in the following 12 months, falls which could be prevented with adequate intervention and management. Such accidents often require hospitalisation and can lead to premature death, especially when associated with a limb fracture. It follows that second-generation systems will require ‘smart’ sensors to monitor long- and short-term trends to prevent and detect falls as quickly as possible without causing too much falls alarms.

The *most important aspect* of these two types of sensors is **the integration of medical and environmental sensors**. This could provide the means to locate where the client is at any particular instant as well as his or her physical condition. Second-generation systems should reduce the number of medical emergencies experienced by elderly people, though it remains to be seen how less intrusive it appears to the client.

- *Third-generation systems* : Although the first two systems of telecare systems are able to reduce anxiety, provide more security to both the client, his or her family and the caregivers, they are not able to provide with innovative services that directly improve the *quality of life* of the elderly people. Limitations of the first two generations of systems are their inability to reduce loneliness and their failure to detect and rectify problems of forgetfulness, attention to oral health, washing of hair and notably urinary incontinence. These matters would be obvious to visitors, but unfortunately could not be appreciated by technical devices. In the belief of the author [2], many such problems could be overcome in the future by using the *virtual neighborhood* concept. In such a community, people would possibly be dispersed geographically over a long distance, but still linked together through network. The means of communication between users and their caregivers could be the domestic television set adapted to function as an interactive videophone with a remote control that could enable the user to operate various tasks without having to move out of the chair. Like he or she could use the television to communicate with his or her caregiver as well as the virtual neighbor who could possibly be located many mile away from his or her house. With such an interactive device in his or her possession, he or she could always "stroll" in his virtual neighborhood to get access to various kinds of virtual community facilities. In such a situation he or she would no more be socially isolated, rather an active participant in the virtual community.

From the organizational point of view, technical solutions must be acceptable to both the health-care staff and the assisted person and should supplement, but *not* replace human carers [15]. Other important aspects of technical solutions are : simplicity of operation and management, availability, reliability or accuracy, and affordability. The general system architecture for such systems of home health care should consist of a central database containing patient data, care plans and other information, and monitoring devices at the home of the patients, generally connected to a monitoring center by a telephone line.

Recently, Automated Voice Messaging (AVM) system has been developed as an adjunct to primary care for the diabetic patients. It inquired about the patient's symptoms, glucose monitoring, foot care, diet and compliance with medication. Patients responded by using their touch-tone telephone key-pads and were given the option to listen to health promotion messages and to report their satisfaction with the calls.

In all telemedicine applications, there is a general lack of formal studies of cost-effectiveness, the partial success of home telecare applications from a commercial point of view shows that they are worth considering if they comply with *at least one* of the following requirements :

1. A high percentage of the population should be involved, so that unit costs decrease; home telecare of the elderly living alone is an example of this.
2. The population should be spread over a region in which communications by road are difficult, so that telecare is cheaper than direct assistance.
3. There should be a need for continuous monitoring [16].

Some problems that may hinder the adoption of home telecare applications are :

1. The general crisis of national health-care systems.
2. Technical difficulties of integrating different devices at home and at the monitoring center.
3. The need for introducing and testing treatment plans which are different from those currently used by physicians.

In summary, the most important aspects of home telecare are :

- Organization and training of personnel.
- Improving quality of care.
- Improving quality of life.
- Better economy.
- Properly assessed technology.

Material and method :

Material :

1. Passive Infra-red (IR) sensors – A total of 9 such sensors were installed in the room which could detect the passage of human movements.
2. Cables to connect the IR sensors with the computer via an I/O parallel card.
3. Software : GARDIEN© (**G**érontologie **A**ssistée par la **R**echerche et le **D**iagnostic des **I**ncidents et des **E**rrances **N**octurnes) – A computer program written in Borland® C++.
4. Computer (Pentium III microprocessor with 64 MB RAM) and printer (Epson Stylus® Color 660).
5. A hospital bedroom (3m by 3m approximately).

Patient :

A written consent was obtained from each patient before they could participate in the research.

Method :

Objective :

The purpose of our research was to study the validity of a system of telesurveillance in elderly patients using an intelligent system consisting of passive IR sensors.

GARDIEN© was created under the TIISSAD project in Toulouse with the aim of remote monitoring and follow-up of chronic patients or elderly (or handicapped) people in order to prevent accidents and aggravation of the diseases. It was implemented at Elisée Chatin, Département Hospitalo-Universitaire de Médecine Communautaire, La Tronche, Grenoble.

Method :

1. Sensors and Network

A hospital bedroom (3m by 3m), at the second floor of Elisée Chatin was selected for the purpose of study. 8 passive IR sensors were installed in the patient’s bedroom known as Intelligent bedroom or “Chambre intelligente” well above the height of a tall person in different walls as shown in Fig. 2.1b and Fig. 2.8. These IR sensors are detectors of human (thermal) movements. The range of these sensors were narrowed down with the use of masks in certain cases, so that they could only detect the passage of human beings while passing below each sensor. In addition, their zone of capture could be manipulated by a pivoting mechanism that permits rotation along an axis. They are named as door (outside), door (inside), wall-door, wall-window, window, bed, center, and toilet sensors. These sensors were connected through cables to an I/O parallel card, which in turn was connected to a Pentium III, 64 MB RAM computer placed at a remote site from the patient's bedroom (Fig. 2.1a).

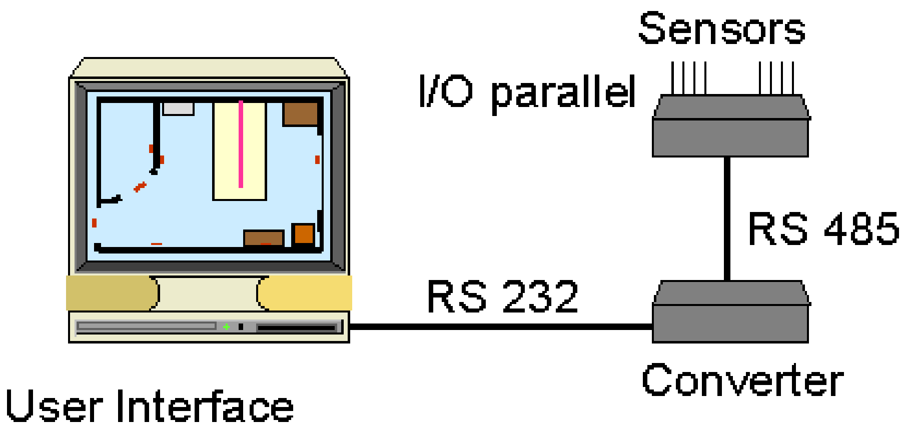


Fig. 2.1a. The GARDIEN© system.

Fig. 2.1b. A sensor installed in the patient's room (Left). The passage to wash basin (Right).

2. Registration of movements during the night

The computer was always kept on throughout the period of research. It switched on automatically every night at 9 p.m. and remained active throughout the night till 6 a.m. Data corresponding to movements were collected twice per second, and stored with indication of time when they differed. This type of data-handling helped to reduce the size of the file that was obtained at the end of the surveillance period every morning.

GARDIEN© registers movements made by the single aged patient staying in the bedroom during the span of 9 hours (from 2100 to 0600 hours on the next morning) and saves them in a *file* named “surveillance du “date”.dat” everyday. The sequence of activation of different sensors results in them being saved sequentially in the file.

3. Addition of a new sensor

Initially, 8 IR sensors were placed in the bedroom according to the plan of the bedroom at Toulouse. But subsequently after 29 nights of observation, it was found that the result obtained in Grenoble were inferior to the one that was observed at Toulouse. It was noted that in Toulouse, the WC and wash basin together were placed inside the toilet, where one such sensor was placed. Whereas in Grenoble, the wash basin was outside the toilet, near to which there was a sensor, but there was no sensor placed inside the toilet. This difference in the plan of the two bedrooms was thought to be the cause of discrepancy between the results obtained at Toulouse and Grenoble. On account of this, a new 9th sensor was installed inside the Toilet by Y-connection to the sensor just outside the toilet near the wash basin as shown in Fig. 2.2. Fortunately, after this minor but significant modification the results showed a marked improvement.

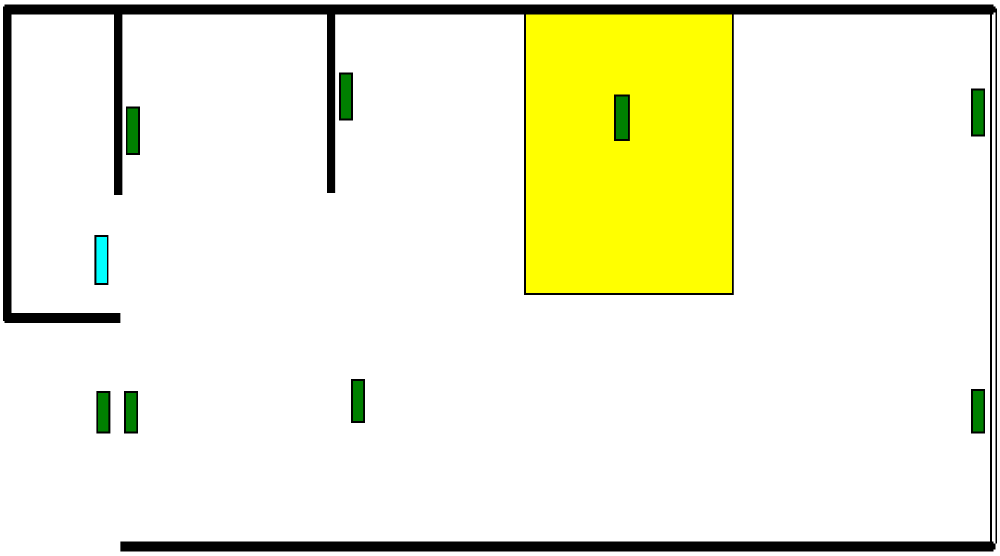


Fig. 2.2. “Chambre intelligente” in Grenoble after implementation of the 9th sensor (light blue) inside the toilet.

```
1            Wed May 02 22:02:26 2001
             Wed May 02 22:02:30 2001
1            Wed May 02 22:02:31 2001
12           Wed May 02 22:02:31 2001
 2           Wed May 02 22:02:32 2001
 23          Wed May 02 22:02:34 2001
  3          Wed May 02 22:02:36 2001
  3      A   Wed May 02 22:02:36 2001
         A   Wed May 02 22:02:37 2001
  3      A   Wed May 02 22:02:38 2001
  3          Wed May 02 22:02:40 2001
             Wed May 02 22:02:41 2001
  3          Wed May 02 22:02:42 2001
 23          Wed May 02 22:02:43 2001
 2           Wed May 02 22:02:44 2001
12           Wed May 02 22:02:45 2001
1            Wed May 02 22:02:45 2001
             Wed May 02 22:02:47 2001
1            Wed May 02 22:02:48 2001
             Wed May 02 22:02:50 2001
1            Wed May 02 22:02:50 2001
             Wed May 02 22:02:51 2001
1            Wed May 02 22:02:54 2001
             Wed May 02 22:02:56 2001
1            Wed May 02 22:02:57 2001
             Wed May 02 22:02:59 2001
1            Wed May 02 22:03:02 2001
             Wed May 02 22:03:06 2001
```

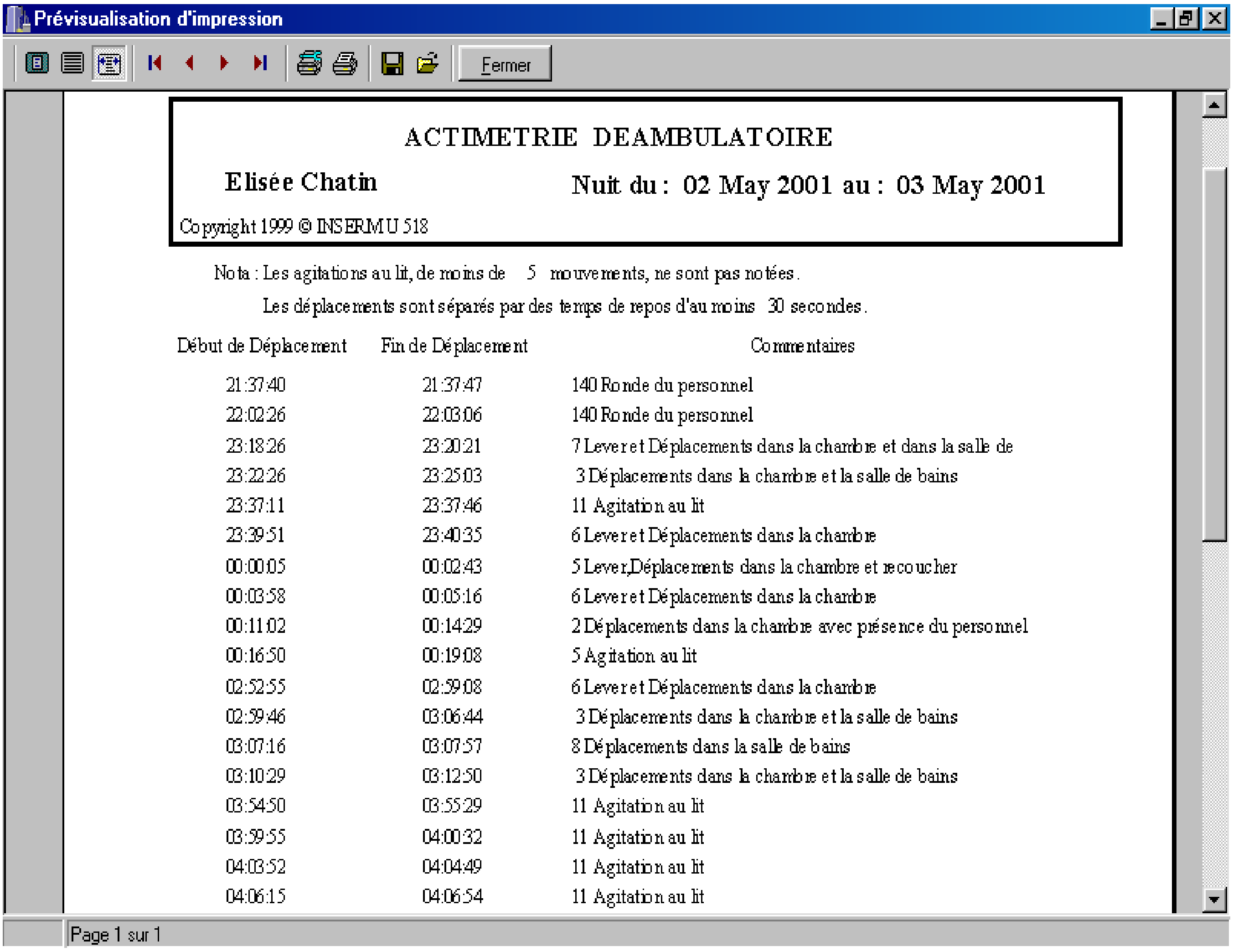
Fig. 2.3. “Ronde du personnel” on analysing manually. It is detected as “Ronde du personnel” by GARDIEN© shown in Fig. 2.4 (second line) and also corroborated with Fig. 2.9, where the time of entry of the night personnel in the document sheet is noted to be 22.00 hours.

4. Document sheet maintained by the night personnel (Fig. 2.9)

In addition, the patient's room was always visited by the personnel during the night. This resulted in more than one person being present in the room during the period of visit by personnel. GARDIEN© is programmed in such a way that it can differentiate the entry and exit of personnel from that made by the patient. The night personnel were given a document sheet to note their time of entry in the room as well as number of persons, duration of stay and any special remarks like fall in the room, the state in which the patient was being found, or the patient found in the corridor, etc.

5. Analysis of the file and its comparison with the report generated by GARDIEN©

Every file that was created during the night was opened with a word processor the following day and printed. An example (sequence) from a portion of a file is shown in Fig. 2.3. This print-out was analysed manually to find out all the activities that took place in the bedroom during the night *taking into account the document sheet filled by the night personnel*. The term manual analysis is described as follows : at first, the file to be analysed was divided into successive different sequences of *valid* movements according to the rules described in the latter part of this section. Next, within each sequence, each sensor was noted with respect to the previous sensor registered in the file. In this manner, all the sensors were analysed within a sequence one after another. The resulting sequence that was found from this analysis was compared with the entry of night personnel *if* noted in the document sheet and then a proper movement name, like "Ronde du personnel, etc.", was assigned to that particular analysed sequence, taken from a list of 25 movements as shown in Table 2.1 at the end of this chapter. Other sequences were analysed in the same manner. The result of this analysis was then compared with the result produced by GARDIEN©, an example of which is shown in Fig. 2.4., *i.e.*, each movement analysed manually was compared with each movement detected by GARDIEN© to see the concordance between the two results.


Prévisualisation d'impression

Fermer

ACTIMETRIE DEAMBULATOIRE

Elisée Chatin   Nuit du : 02 May 2001 au : 03 May 2001

Copyright 1999 © INSERM U 518

Nota : Les agitations au lit, de moins de 5 mouvements, ne sont pas notées.

Les déplacements sont séparés par des temps de repos d'au moins 30 secondes.

Début de Déplacement	Fin de Déplacement	Commentaires
21:37:40	21:37:47	140 Ronde du personnel
22:02:26	22:03:06	140 Ronde du personnel
23:18:26	23:20:21	7 Lever et Déplacements dans la chambre et dans la salle de
23:22:26	23:25:03	3 Déplacements dans la chambre et la salle de bains
23:37:11	23:37:46	11 Agitation au lit
23:39:51	23:40:35	6 Lever et Déplacements dans la chambre
00:00:05	00:02:43	5 Lever,Déplacements dans la chambre et recoucher
00:03:58	00:05:16	6 Lever et Déplacements dans la chambre
00:11:02	00:14:29	2 Déplacements dans la chambre avec présence du personnel
00:16:50	00:19:08	5 Agitation au lit
02:52:55	02:59:08	6 Lever et Déplacements dans la chambre
02:59:46	03:06:44	3 Déplacements dans la chambre et la salle de bains
03:07:16	03:07:57	8 Déplacements dans la salle de bains
03:10:29	03:12:50	3 Déplacements dans la chambre et la salle de bains
03:54:50	03:55:29	11 Agitation au lit
03:59:55	04:00:32	11 Agitation au lit
04:03:52	04:04:49	11 Agitation au lit
04:06:15	04:06:54	11 Agitation au lit

Page 1 sur 1

Fig. 2.4. showing result obtained by GARDIEN© on the night of 2nd May 2001.

Certain rules were applied while analysing the print-outs manually and comparing them with the results obtained from GARDIEN©. When a sensor is activated by the passage of a human being, it becomes *inactive* after a certain period of time which can be *variable* depending on the duration of activity taking place under the sensor. The time when it become *inactive* was noted and from that moment any further activation of the same or another sensor during the next 29 seconds was sought. If the following activation took place after 30 seconds or more, it was then considered to be a part of another movement, otherwise it was considered to be within the same movement. In addition, the total number of activation of sensors in a sequence was chosen to be a minimum of *five* in order to be considered as a complete sequence of movement. GARDIEN© is provided with a facility to alter these two parameters before obtaining the result. As such, different thresholds can be chosen for delineating a movement, like increasing the duration of interval from 30 seconds to two minutes and changing the minimum number of activation of sensors in each movement from 5 to 15, and so on (Fig. 2.6).

Fig. 2.5.

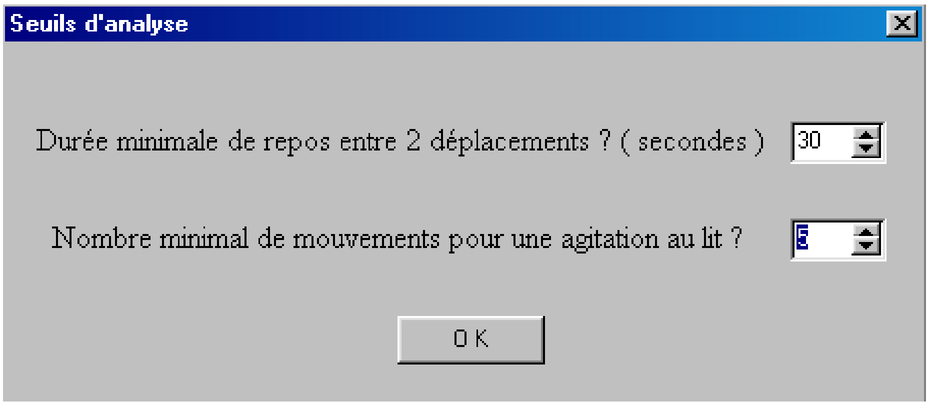


Fig. 2.6.

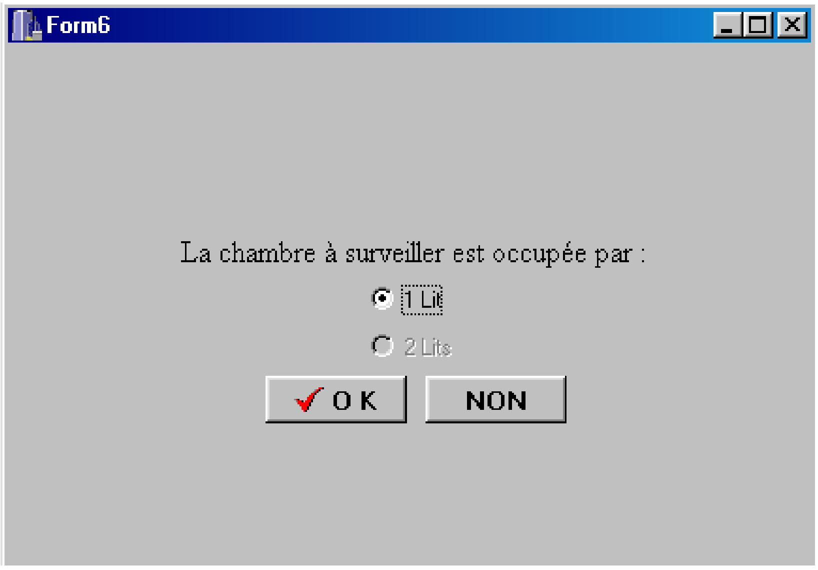


Fig. 2.7.

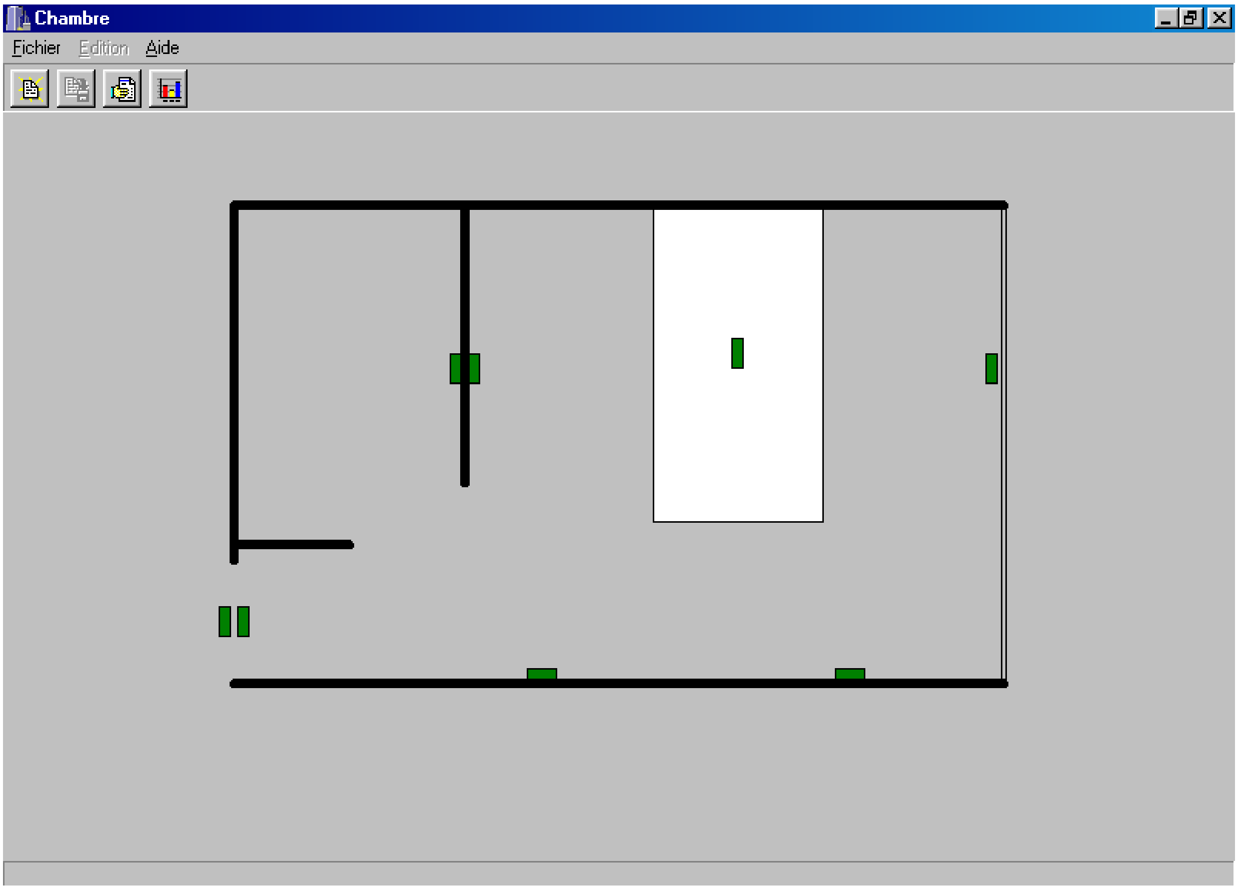
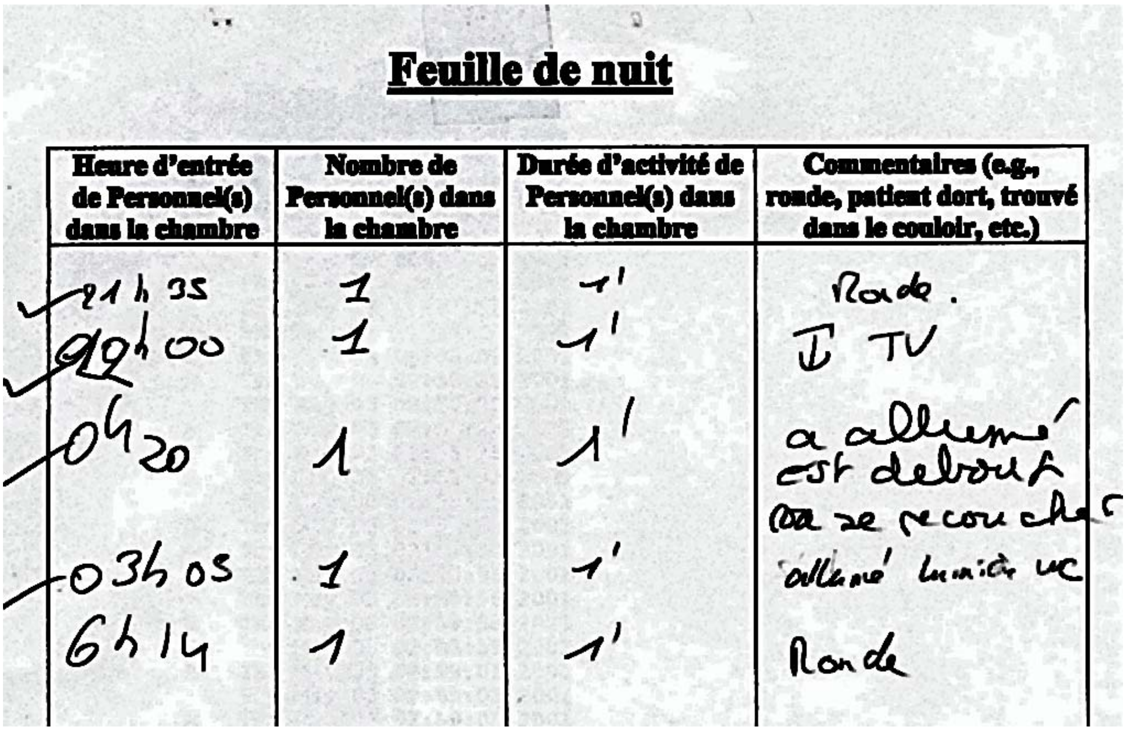


Fig. 2.8. The plan of the patient’s bedroom in Toulouse. Compare it with Fig. 2.2.

1. Plusieurs personnes dans la chambre
2. Déplacements dans la chambre
3. Déplacements dans la chambre et la salle de bains
4. Déplacements dans la chambre et la salle de bains puis recoucher
5. Déplacements dans la chambre et recoucher
6. Lever, Déplacements dans la chambre et recoucher
7. Lever et Déplacements dans la chambre
8. Lever, Déplacements dans la chambre et la salle de bains
9. Déplacement dans la salle de bains
10. Agitation au lit
11. Lever ou agitation au lit ou déplacements près du lit
12. Ronde du personnel
13. Lever du patient et sortie de la chambre
14. Patient est sorti de la chambre
15. Ronde du personnel et agitation au lit
16. Retour et sortie du patient
17. Recoucher du patient accompagné par le personnel
18. Patient est sorti de la chambre et raccompagné par le personnel
19. Retour du patient et recoucher au lit
20. Retour du patient dans la chambre
21. Lever, déplacements dans la chambre et visite du personnel
22. Déplacements dans la chambre et visite du personnel
23. Déplacements dans la chambre avec présence du personnel
24. Déplacements dans la chambre, visite du personnel et recoucher/agitation au lit
25. Lever, Déplacements dans la chambre et la salle de bains et recoucher

Table 2.1. Shows the list of movements that GARDIEN© is able to detect.



Feuille de nuit

Heure d'entrée de Personnel(s) dans la chambre	Nombre de Personnel(s) dans la chambre	Durée d'activité de Personnel(s) dans la chambre	Commentaires (e.g., ronde, patient dort, trouvé dans le couloir, etc.)
21 h 35	1	1'	Ronde.
22h 00	1	1'	J TV
04 20	1	1'	a allumé est debout va se recoucher
03h 05	1	1'	allumé lumière WC
6h 14	1	1'	Ronde

Fig. 2.9. A sample document sheet filled by the night personnel.

Observation and Results :

Following installation of the new sensor, 97 nights were observed with GARDIEN©. There were 4 patients in succession who occupied the room during this observation period (Table 3.1).

Serial no.	**Number of nights observed with the new sensor**	**Age (years)**	**Sex**	**Diagnosis**	**Ambulatory**	**MMSE* (30)**	**ADL** (6)**
1	3	77	Female	Road traffic accident	Yes	--	3.5-5.5
2	46	77	Male	Alzheimer's Disease	Yes	13	--
3	10	79	Female	Dislocation of the left shoulder	Yes (but rarely moved on her own)	--	3.5
4	38	93	Male	Senile Dementia	Yes	17	--

Table 3.1. Information regarding the patients who participated in the research.
**MMSE = Mini-Mental State Examination (Max. score 30)*
***ADL = Activities of Daily Living (Max. score 6)*

1. Number of *movements analysed manually* taking into account the document sheet filled by the night personnel = 1637 (note : except 3 nights, the document sheet was always done by the night personnel)
2. Number of *movements GARDIEN© was able to detect* = 1627 (*i.e.*, 10 movements were not detected by GARDIEN©)
3. Number of *movements detected by GARDIEN© that had the same time-interval compared to the movements analysed manually* = 1571 (*i.e.*, approximately 96% of the movements analysed manually were noted to have the same time-interval as detected by GARDIEN©)
4. Number of *movements detected by GARDIEN© that had been analysed manually in the same manner as detected by GARDIEN©* = 1450 (*i.e.*, 88.6% of the movements analysed manually were interpreted correctly by GARDIEN©)

5. Number of *entries made by the night personnel in the document sheet* = 341. Of which, number of *times GARDIEN© was able to register it at the same time when it was noted by the night personnel* = 332 (*i.e., sensitivity* of the system to detect any reported event = 97.4%)

GARDIEN50© is a program that had been developed to test proper functioning of GARDIEN©. It has all the same qualities of GARDIEN©, except that it starts to function at the 50^{th} minute of an hour and after running for 15 minutes, it stops exactly at the 5^{th} minute of the following hour, i.e., if it starts at 1450 hours, then it will stop at 1505 hours. During this short period of activity, it will function and register all the movements in the room in exactly the same manner as GARDIEN© would do so during the night. This is done primarily to *test the integrity of the sensors in capturing and registering the movements* in the file that is created. 5 such tests were done, each lasting for a period of 15 minutes. Every gross physical movement that was enacted *voluntarily* within the room during this period were meticulously noted. After each test, print-out of the file with a word processor was taken, which were subsequently analysed manually taking into account the report of the activities noted during the stay in the room. Of the 36 movements enacted, GARDIEN50© was able to accurately *register* all the sequences of activities exactly in the same manner in which it was enacted.

All the movements that took place within the room during the period of research are also categorically placed according to the type of movements analysed manually and the its detection by GARDIEN©. This is depicted in Table 3.2 and graphically in Fig. 3.1. The numbers corresponding to each movement are taken from Table 2.1.

Movement type	Movements analysed manually	Movements detected correctly by GARDIEN©
1	**19**	**19**
2	374	322
3	95	70
4	46	44
5	118	108
6	57	47
7	132	118
8	59	46
9	**10**	**10**
10	231	225
11	**83**	**83**
12	129	126
13	28	14
14	16	4
15	87	84
16	3	2
17	22	19
18	4	3
19	8	6
20	3	2
21	12	8
22	15	13
23	0	0
24	21	16
25	65	61

Table 3.2. Table showing the comparison between the movements analysed manually and those detected correctly by GARDIEN© according to each type of movement. Movement 1 (“Plusieurs personnes dans la chambre”), 9 (“Déplacements dans la Salle de bains”) and 11 (“Lever ou agitation au lit ou déplacements près du lit”) are shown in **bold** as their detection rate was 100%. The numbers corresponding to each movement are taken from Table 2.1.

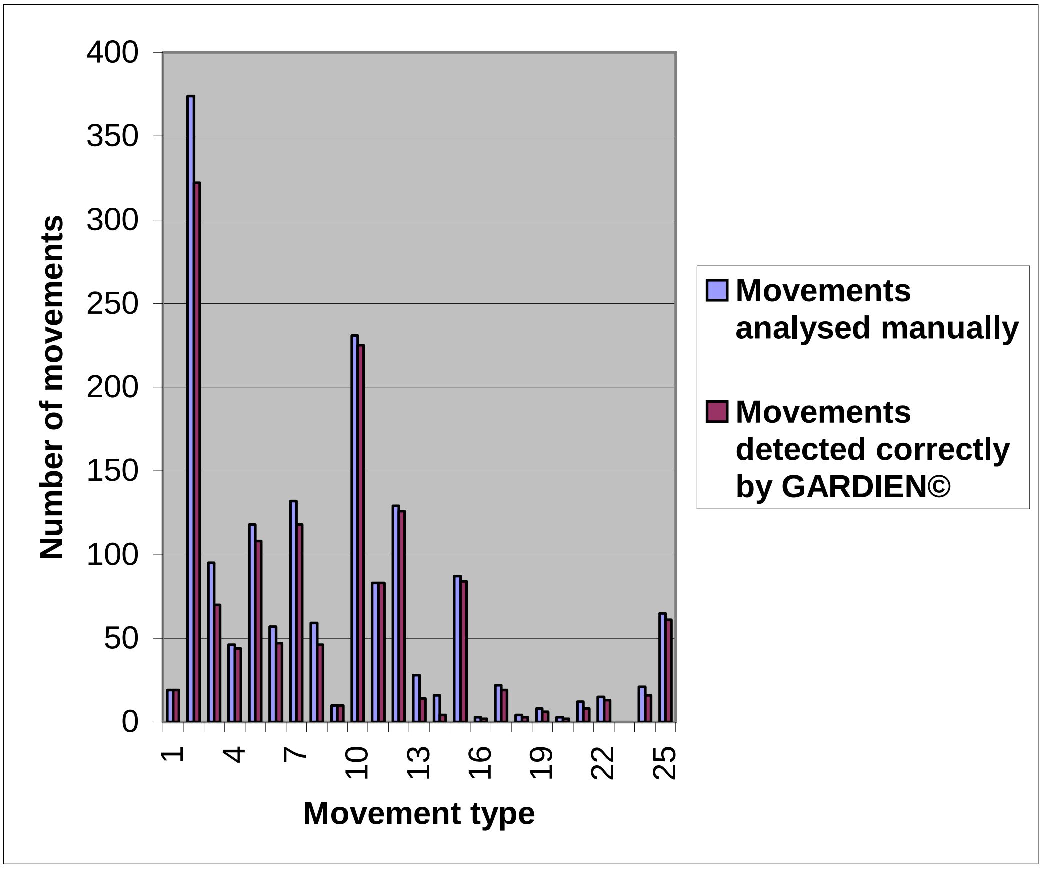


Fig. 3.1. Graphical representation of the comparison between the movements analysed manually and those detected correctly by GARDIEN© according to each type of movement. The numbers corresponding to each movement are taken from Table 2.1.

Two of the patients, both male, aged 77 and 93 years, suffering from Alzheimer's Disease and Senile Dementia (as shown in Table 3.1) were observed for a period of 46 and 38 nights, respectively. The observations regarding the total number of movements compared to agitation in the bed are shown graphically in Fig. 3.2 and Fig. 3.3.

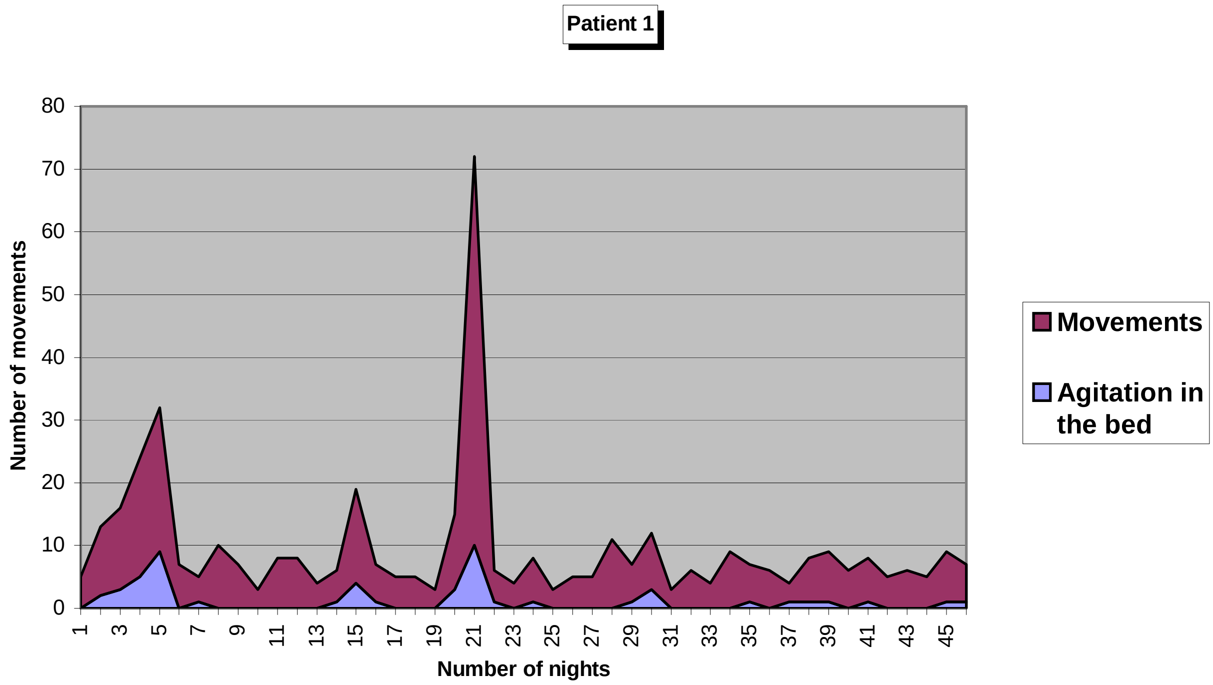


Fig. 3.2. Figure showing the total number of movements that occurred in the room in relation to agitation in the bed in a male patient aged 77 years. Note the excessive agitation on day 21.

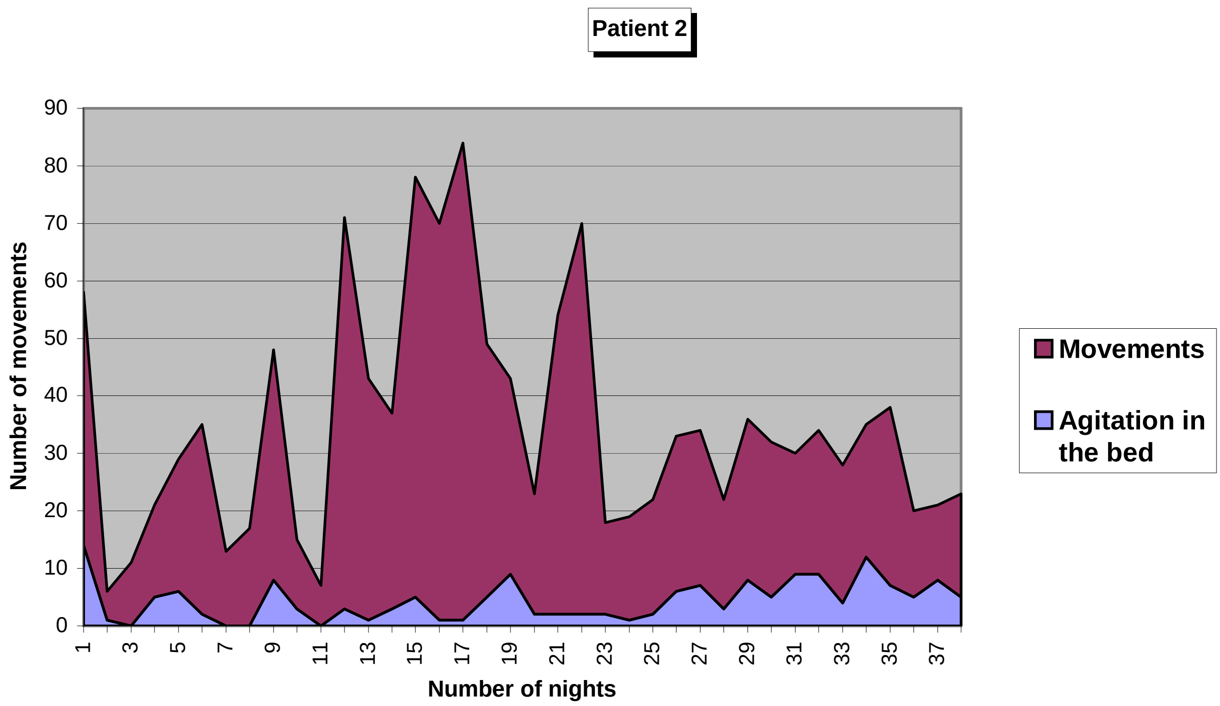


Fig. 3.3. Figure similar to the one before in a male patient aged 93 years. Note the overall hyperactivity during the first 3 weeks.

Discussion :

Hospitalised elderly patients tend to be more frail, ill and dependent than their community dwelling peers. Most of the telemedicine technologies are concerned with the care of the elderly people living in the community, but previous studies conducted at LI2G showed that there is a distinct necessity of having a system of passive telealarm for the care of the elderly patients admitted in a geriatric hospital [17]. Patient who are at risk of suffering a fall, wandering out of their bedrooms, or who have poor safety awareness like the demented need a system of teleassistance in addition to the conventional system of summoning help through the use of bed-side alarms or by other means. With a view to improve the care of the elderly admitted in the hospital, GARDIEN©, a system of telesurveillance consisting of passive IR sensors was installed in a patient's bedroom at the second floor of Elisée Chatin, CHU, Grenoble.

The observations started from mid-November 2000. As mentioned earlier, the discrepancy in the results between Toulouse and Grenoble prompted us to make a minor, though significant change in the arrangement of the IR sensors by the addition of a new 9th sensor within the toilet in Y-connection to the sensor placed just outside the toilet. Subsequently, observation for 97 nights showed that there is 89% ***reliability*** (qualitative) of the results obtained from GARDIEN©, which in other words means that 89% of the movements analysed manually were accurately detected in the same manner by GARDIEN©. This percentage of accuracy was consistent throughout the period of observation, that is there wasn't significant fluctuation in *the day to day* results obtained, which indicates that the system has a very high degree of ***precision***. This is manifested in **the coefficient of correlation** (Fig. 4.1) between the two sets of data for 97 nights, one being the total number of movements analysed manually every day and the other being the total number of movements interpreted correctly by GARDIEN© on the same day, as **0.99**.

It was noted from the document sheet obtained from the night personnel that GARDIEN© was able to *pick-up* 97.4% of activities noted by them. In addition, testing with GARDIEN50© showed that *all* the gross movements were always *picked-up and registered* in the file by the system. So, *the most important step in determining the* ***accuracy or reliability*** *of the system was to find how the program (algorithm)* ***treats or analyses the data*** *thus obtained*. That is whether GARDIEN© is able to interpret the data in the same manner as it would intuitively appear to the person analysing the data manually, which was found to be 89%.

So far, most of the telesurveillance systems that have been developed or tested, used a system of multisensors in which IR sensors are used along with other types of sensors like door opening sensor (magnetic switch), touch detector (on furniture), room temperature sensor, bed movements detector, room humidity sensor, smoke detector or fire-alarm, Carbon dioxide sensor (for static presence of a person), fall sensor (accelerometer / "actimeter"), etc. [8][9][10][11][12][18][19]. In all these cases, the use of multisensor system corroborates the data obtained from different sources and combines information to arrive at a result regarding activity of a person within an intelligent habitat. The installation of a multisensor system increases the complexity of the habitat in addition to increasing the expenditure. Moreover, the IR sensors that were used in all these cases, only detected the presence or absence of a person by noting the movements caused by him or her.

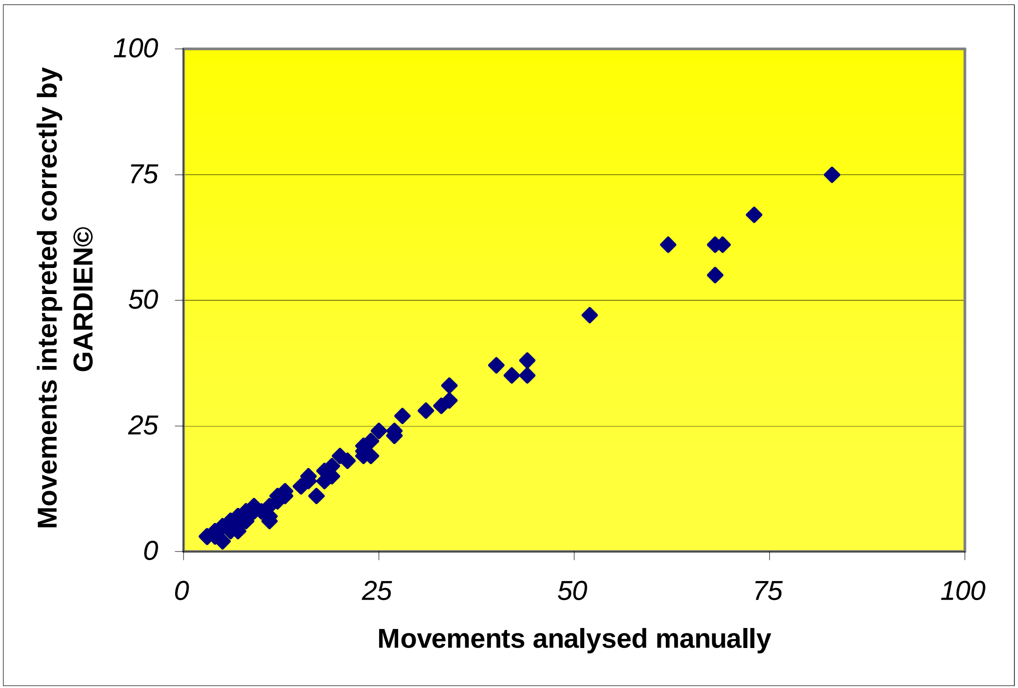


Fig. 4.1. Graph showing the correlation between the movements analysed manually with the movements interpreted correctly by GARDIEN©. The coefficient of correlation is found to be 0.99, which indicates that the system has a very high degree of precision.

GARDIEN©, on the other hand, is developed by using only a single type of sensor, that is IR sensor, which by its intelligent programming algorithm could not only detect the presence or absence of a person, but also detected with precision the type of activities done by the person within the room including his or her exit from the room. This is an important aspect of the system since it permits distinction between the entry and exit of night personnel with that of the patient. This feature could well, in future, be combined with a system of *telealarm* that can alert the caregivers in *real-time* whenever the patient tries to leave the room (but certainly not when there is entry and exit of the night personnel), which are many times associated with falls or getting injured in the corridor, etc. [17]. The *simplicity* of installation of IR sensors within a room is a large plus point, since no other type of sensor is required. In addition, there is *less expenditure* involved with the use of only one type of sensor.

The next important aspect of GARDIEN© lies in the fact that it is a software that is *upgradable* and so can always be replaced by a newer version with added features to *adapt* to changes that may be employed in future. So it has a *futuristic vision* that looks ahead and is flexible to any new implementation.

The patients who stayed in the room during the period of observation did not feel any discomfort with the system, though all of them were aware that they were being surveyed by a system of sensors. They didn't perceive it to be intrusive in their daily life during their period of stay. They or their relatives wanted to make sure that is was *not* a camera, but a simple sensor capable of detecting movements. So it can be postulated that GARDIEN© is generally perceived to be *non-intrusive* by the elderly patients admitted in the hospital and that they were *tolerant* to the system.

A very important feature of GARDIEN© is that *nocturnal actimetry* of the persons living in the room can be done. There is no other reliable means to follow the activities of a person in a hospital room during the night. History obtained from the nurses cannot be relied upon as well as trends cannot be picked up. Also, activities during the daytime is completely different from that of the night as the patient may be agitated only during the day or the night. This may have important behavioral and therapeutic implications as illustrated in Fig. 3.2 and Fig. 3.3 (both figures are constructed by taking data obtained from manual analysis of the files of these two patients). Fig. 3.2 shows the total number of movements (brown) that took place within the room occupied a by 77-year-old patient in relation to agitation in the bed (blue) for a period of 46 nights. It can be seen that generally there were 10 or less movements each night, except in the beginning, when he was somewhat agitated for 4 nights and then on 21st night when he was excessively agitated (Fig. 4.2). It can also be observed that whenever there was an increase in the total number of movements in the room, there was a corresponding increase in the number of agitation in the bed. This is reflected in **the coefficient of correlation** between the two, which is found to be **0.86**. As he is known to be a patient of Alzheimer's disease, further analysis of such activities can be extremely useful to study the pattern of nocturnal behavior in those type of patients.

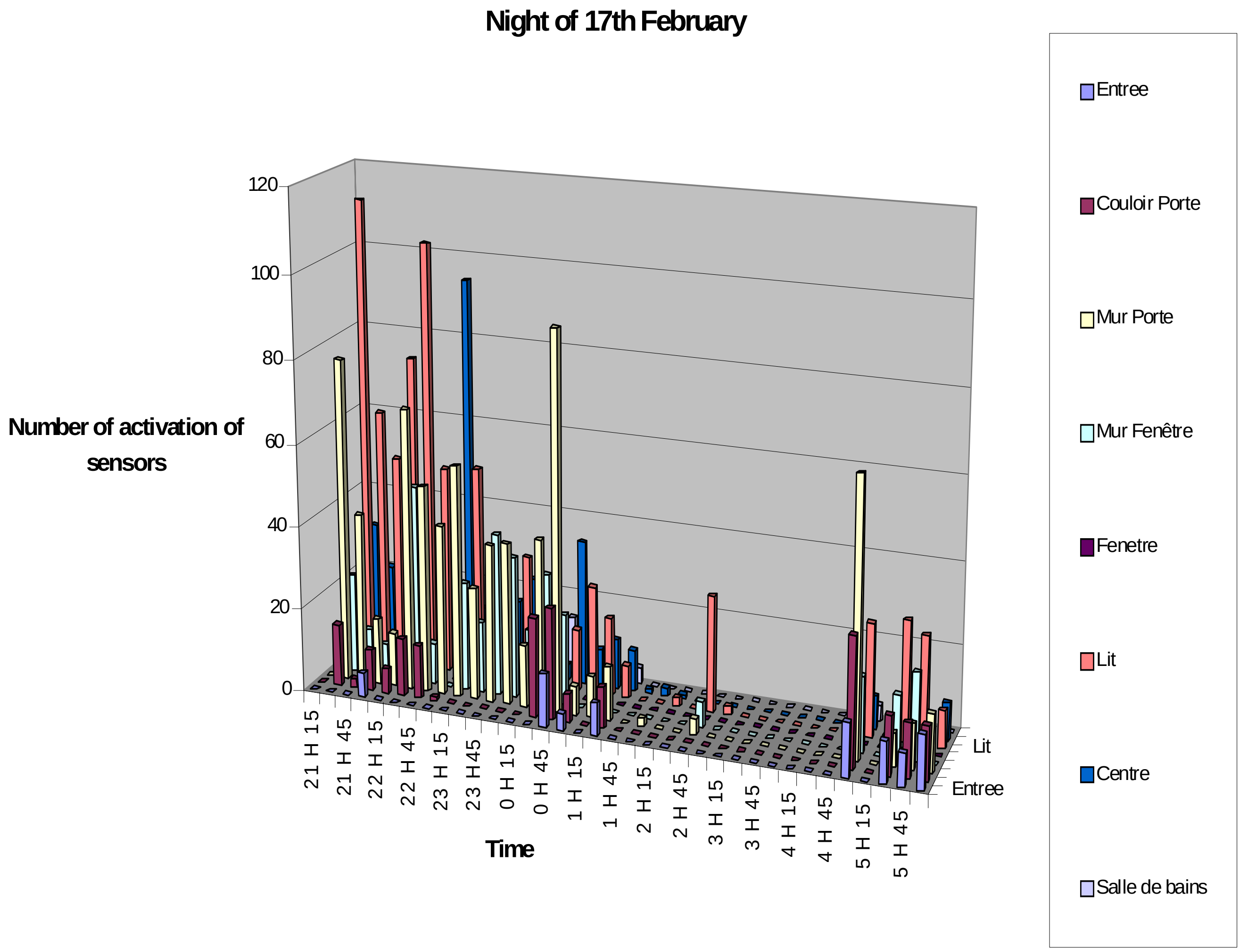


Fig. 4.2. Figure showing excessive agitation by the patient on the 21st night followed by a period of quietness in the latter part of the night.

On the other hand, Fig. 3.3 shows the nocturnal behavior in a 93-year-old patient of senile dementia who was observed for a period of 38 nights. It can be seen that during the first 3 weeks of his stay (22 nights), there was excessive overall agitation. This period was intercepted by deep notches as can be seen in the figure, which showed that his level of overall agitation fluctuated widely during this period. In the last two weeks of his stay, there was considerable decline in the level of overall agitation as well as its daily fluctuation, although the amount of agitation in the bed gradually increased in relation to the overall agitation (Fig. 4.3). The average total number of movements in the room during the first 22 nights was 36.77, with the average number of agitation in the bed being 3.31. During the next 16 nights, the average total number of movements in the room was 22, with the average number of agitation in the bed being 5.81. Also, there was no correlation between the total number of movements in the room and the number of agitation in the bed as seen from **the coefficient of correlation** being **-0.003**. Hence, by comparison of the pattern of nocturnal activities between the two patients it can be seen that they have quite different characteristics in their nocturnal behavior, which can be attributed to *the diagnosis and the stage of the disease* as well as *therapeutic measures* taken on them.

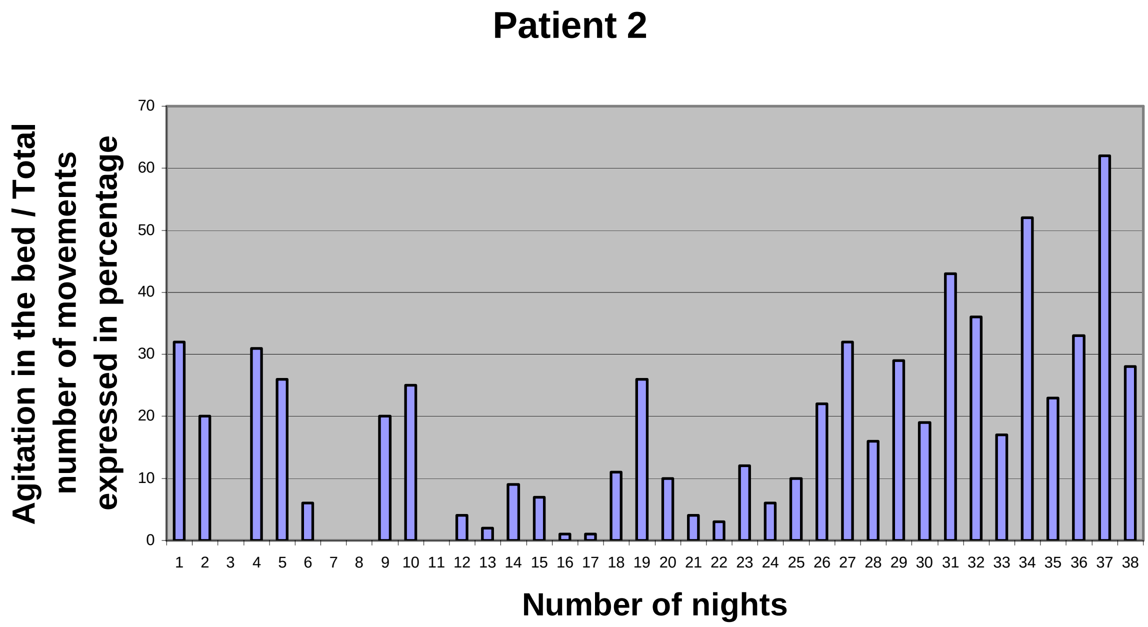


Fig. 4.3. Figure showing gradual increase in the amount of agitation in the bed in relation to the total movements in the room expressed in percentage, in a 93-year-old patient of senile dementia.

Apart from the what is described above, there can be plenty of other aspects which remains to be explored with GARDIEN©. For instance, the onset of frequent passage to the toilet in the night could herald incipient cardiac failure, poorly controlled Diabetes Mellitus, or polyuria in the early stage of Chronic Renal Failure that may in turn alert the physician to check for these aspects. Motor activity in the elderly patients can be studied under the influence of different odors, music, or other external agents capable of inducing changes in behavior, etc. Studying behavior trends in relation to treatment may also be implicated in planning therapy of the patients in future. In addition, sleep patterns may be discovered in patients with such a non-invasive and non-intrusive system. For instance, a patient with a known seizure disorder showing excessive agitation in the bed on a particular night could signal a convulsion and in turn may be programmed to activate the alarm. On the other hand diminished activity in the bed in a bed-ridden patient could forewarn the onset of bed-sores. In such patients, it would be worth finding the activities of the night personnel too to note if they frequently changed the bed-position of such bed-sore prone patients.

As mentioned in the beginning that GARDIEN© is an environmental sensor, it can very well be *compatible* to be used along with other medical or body-attached sensors, like those devices measuring heart rate, ECG, blood pressure, or fall detectors (accelerometers).

Finally, general trend in a patient could serve as a learning process for the program, which could be set to auto-detect any abnormal deviation from the usual pattern of activities. As this type of research is conducted in many parts of the world to enable a system become intelligent enough through learning processes [20] to distinguish between normal and abnormal behaviors, such developments could well in future be implemented in GARDIEN© making it a very powerful, active, real-time, surveillance system that would work 24 hours a day, thus improving the quality of life and providing better quality of patient care.

Conclusion :

GARDIEN©, a system of nocturnal telesurveillance using passive IR sensors, was installed and tested for 97 nights at Elisée Chatin, CHU, Grenoble. At the end of the study, it was found that it is capable of identifying approximately 89% of the activities that took place in the room from 9 pm to 6 am in the next morning. In addition, it was extremely precise in registering the movements as day to day variation in the result was found to be negligible, given by the coefficient of correlation being equal to 0.99. It now remains to be connected to a system of telealarm to see if it can alert the night personnel in real-time in case of exit of the patient from the room. It would at the same time provide a means of patient surveillance for the doctors interested to know the nocturnal activities of the patient. Both these aspects of the system would, in future, improve the security of the fragile elderly at his or her home or in the hospital without disturbing his or her daily life as he or she will not have to wear any device.

I would like to continue my research by completing a thesis in “Génie Biologique et Médical” concerning the actimetry of aging population and the characterisation of normal and pathological human behavior in fragile elderly people in his or her habitat with the help of a system capable of measuring activities of daily life. The main interest of my work would be spatio-temporal telesurveillance of persons by analysis of the data derived from sensors in order to study the evolution of the activities of the person with respect to time. The approach will primarily consist of correlating ADL and IADL with the activities measured by sensors.

Glossary of acronyms used :

- ADL = Activities of Daily Living.
- CHU = Centre Hospitalier Universitaire.
- GARDIEN© = Gérontologie Assistée par la Recherche et le Diagnostic des Incidents et des Errances Nocturnes.
- IADL = Instrumental Activities of Daily living.
- LI2G = Laboratoire Interuniversitaire de Gérontologie.
- MMSE = Mini-Mental State Examination.
- PASE = Physical Activity Scale for the Elderly.

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Abstract§

Purpose : To study the validity of a system of telesurveillance in elderly patients using a passive infra-red (IR) sensor network and a software.

Method : GARDIEN©, a system of passive IR sensor network, is connected to a computer that is placed at a remote site from the patient. It switches on automatically every night at 9 p.m. and remains active throughout the night till 6 a.m. in the next morning. Data corresponding to movements are collected twice per second, and stored in a file with indication of time when they differ. We have analysed, for 97 nights, every sequence of movements from each file that is created every night and correlated it with the reports of motor activities made by the night personnel to find out whether the analysis of sequences of movements within the file correlates with the interpretation of sequences of movements made by GARDIEN©.

Results : We have analysed a total of 1637 possible sequences of movements made by the patient or the personnel. Of these, GARDIEN© is able to correctly identify 1450 (89%) sequences in the same manner as being found by manually analysing each sequence taking into account the document sheet filled by the night personnel. The day to day variation in the result has been precise as given by the coefficient of correlation being equal to 0.99 between these two sets of data.

Conclusion : GARDIEN© will be able to warn patients' caregivers in real-time by an alarm in the future. Hence, it will reduce the burden of health caregivers and consequently improve elderly patient's safety without encroaching the privacy and also without altering the lifestyle of the patient as he or she would not have to wear any device.

§ Poster presentation in the 17th World Congress of International Association of Gerontology, Vancouver, Canada, 1-6 July, 2001. **S. Banerjee**, F. Steenkeste, P. Couturier, M. Debray, A. Franco. *GARDIEN© : A system for detecting nocturnal motor activity in elderly patients in a hospital room.*