Mobility in Hospital Work: Towards a Pervasive Computing Hospital Environment

Elisa B. Moran¹, Monica Tentori¹, Victor. M. Gonzalez², Jesus Favela¹ and Ana. I. Martinez-Garcia¹

¹Computer Science Department, CICESE
Km. 107 Carr. Tijuana-Ensenada, CP 22860, Ensenada, B.C, Mexico
{elmoran, mtentori, favela, martinea}@cicese.mx
²School of Informatics, University of Manchester, United Kingdom
vmgonz@manchester.ac.uk

Abstract. Handheld computers are increasingly being used by hospital workers. With the integration of wireless networks into hospital information systems, handheld computers can provide the basis for a pervasive computing hospital environment; to develop this, designers need empirical information to understand how hospital workers interact with information while moving around. To characterize the medical phenomena we report the results of a workplace study conducted in a hospital. We found that individuals spend about half of their time at their base location, where most of their interactions occur. On average, our informants spent 23% of their time performing information management tasks, followed by coordination (17.08%), clinical case assessment (15.35%) and direct patient care (12.6%). We discuss how our results offer insights into the design of pervasive computing technology, and directions for further research and development in this field such as transferring information between heterogeneous devices and integration of the physical and digital domains.

Keywords: mobility, hospital work, pervasive computing, mobile computing, workplace studies, handheld computing, context-aware computing.
1 Introduction

Hospital staff face working conditions that are substantially different from those of office workers, for which traditional desktop computers were developed (Bossen, 2002; Bardram and Bossen, 2005; Sharma et al., 2006). Most hospital staff need to move continuously around the premises to access people, knowledge, and resources in order to perform their work effectively (Bardram and Bossen, 2003). Thus, mobility characterizes work in these environments. For instance, physicians make daily rounds to assess and diagnose patients, changing their location to find colleagues or locate artifacts (patient records, x-ray images, medications) placed in bed wards, laboratories or offices. Therefore, information in hospitals is not generally concentrated in a single place, but distributed among a collection of artifacts in different locations. Consequently, hospitals can be seen as an information space and it is by "navigating" this space that hospital staff can access the information required (Bossen, 2002).

Hospital workers make decisions and act highly influenced by their location, that of others with whom they collaborate, and that of the artifacts required to perform their daily work, such as patient records or specialized equipment, (Munoz et al., 2003). Location, for instance, is useful to determine the type of information hospital workers might require at a given moment. These working conditions call for a new computing paradigm for hospital work, one that supports collaboration and coordination, mobility, seamless interaction with heterogeneous devices, and frequent task switching.

These challenges are motivating the widespread adoption of handheld computers in support of hospital work. Physicians, in particular, are increasingly using handheld computers in their professional practice. It was estimated that about 40% of practicing physicians in the U.S. used Personal Digital Assistants (PDAs) in 2004, up from 19% in 2001 and more than four times more than the overall percentage rate of consumer adoption (Chin, 2005). In fact, several medical schools in the U.S. are requiring students to have a handheld computer. Such an instance is UCLA’s David Geffen’s School of Medicine that established this requirement “to enable ‘point of contact’ access to information resources; and to prepare students for practicing medicine in the 21st century” (David, 2005). This trend has generated interest in the development of medical applications for PDAs and evaluating their use (Fischer et al., 2003; Lapinsky, 2001).

To date, the most popular handheld medical applications are the ones that provide access to reference material, such as pharmacological databases (Lapinsky, 2004). In addition, there is a tendency to use PDAs wirelessly connected to a hospital information system, where this can give physicians access to patient medical records from anywhere within the hospital (Han et al., 2005; Wang and Du, 2005). Even with their limited screen size there are clear advantages from having this increased availability of information.

A more recent trend in supporting mobile hospital workers includes the development of pervasive computing environments (Bardram, 2004) and location-aware information systems (Munoz et al., 2003). These efforts aim at providing hospital staff with access to relevant information from anywhere within the hospital and on a variety of heterogeneous devices. The design of these systems has been inspired by user studies from which a comprehensive understanding of work practices has been developed. To help measure the impact of these technologies, possible barriers for its adoption, and propose new directions for research in this area, we conducted a workplace study. This paper presents the results of this study aiming to characterize the medical phenomena, provide a ground base against which to compare the impact of mobile and pervasive
computing technology once introduced, as well as, some of its implications for the design of mobile and pervasive computing technology to support hospital work.

2 A hospital as a pervasive computing environment

The hospital as a pervasive computing environment is a vision of a highly interactive workplace, where hospital staff can access relevant medical information, through a variety of heterogeneous devices, and can collaborate with colleagues taking into account contextual information. Over the last few years, research has been conducted towards the design of ubicomp solutions in support of hospital work. We have already developed important elements of this vision (Munoz et al., 2003; Favela et al., 2004), which provide support for the following functionality:

2.1 Ubiquitous access to medical services and information

Hospital staff carry a handheld computer connected to a wireless network, and use semi-public displays and other devices embedded within the environment. Through these devices hospital workers can access medical records, laboratory results, and other hospital services during their daily work. For instance, a physician might request a laboratory analysis using a PDA, and later, visualize the laboratory results or X-ray images from a large public display to discuss them with a colleague.

2.2 Awareness of the location of users and devices

The ubiquitous environment monitors the location of hospital staff. The users’ location is estimated through triangulation from the signal strength of the handheld device with an approximate maximum error of one meter around the user’s actual position. This information is displayed as a list of users identifying their presence, as in instant messaging systems (figure 1a), or in a floor map (figure 1b).

![Figure 1](image)

Figure 1 The user uses the handheld to know the availability and location of users and services (a, b) and to send context-aware messages (c)

2.3 Context-aware communication

Hospital staff can send messages depending on environmental conditions. As an example, a physician can send a message that will be delivered to the doctor responsible for a patient in the next shift when the laboratory results are ready (figure 1c). The sender does not need to know a priori the identity of the doctor that will be attending the patient nor the time when the laboratory results will become available.
2.4 Context-aware access to relevant medical information

To provide relevant information to users, the system takes into account contextual information, such as the user’s identity, role, location, time, and status of an information artifact (e.g. availability of laboratory results). Thus, when a physician, carrying a PDA, is near a patient, the system offers to display the clinical record of the patient.

2.5 Context adaptation and personalization

Contextual information is also taken into account to adapt and personalize the presentation of information to the user. Thus, when a physician approaches a public display (figure 2), it shows only the physician’s patients, messages, and the location of others with whom s/he may require to interact.

![Figure 2](image)

Figure 2 The semi-public display adapts to the user’s presenting relevant information and facilitating collaboration

2.6 Information transfer between heterogeneous devices

Hospital staff can transfer information from public spaces to personal devices. For instance, after two colleagues carrying their PDAs and discussing a clinical case using the public display, one of the physicians might want to keep a link to this case in the PDA for further review. The user only needs to transfer information between the display and the PDA by dragging the file to the proxy representing the user in the display.

The design of the pervasive hospital is grounded on work studies carried out in real hospital environments (Bardram, 2004; Favela et al. 2004). However, although these studies provide a general understanding from which design can be inspired, we still need to assess how this technology will impact daily work in the hospital. To this aim, we conducted a study addressing questions such as: can this technology enable hospital workers to spend more time on patient care rather than performing clerical tasks? For this we need to know, how mobile are hospital workers and what motivates their change of location? How often do they interchange information? What are the main artifacts used and how often are they being used? In the next section we describe the study aimed to address these questions, to help validate the pervasive computing technology being proposed, as well as to provide new insights for the design of ubicomp technology.
3 Workplace study

For the last two years, we have conducted a series of workplace studies in a mid-size public hospital in the city of Ensenada, Mexico. As part of those efforts, we conducted a specific study with the objective of: (1) consolidating a conceptual understanding of those hospital workers’ interactive behaviors during their everyday practices; and (2) use that information to produce a characterization of those behaviors informing the design of pervasive computing technologies.

3.1 Characteristics of subjects

The data were collected from observations of six medical workers including two nurses, two physicians and two medical interns. Those roles were selected because they experiment high mobility and are responsible for patient care. Each subject was introduced to the study, and was asked to participate voluntarily. Figure 3, shows pictures of the hospital while working during a day of observation.

![Figure 3](image)

Figure 3  Hospital workers during one of the observation days. (a) A head nurse and medical intern consulting a medical note and (b) Medical interns in a ward round discussing a clinical case and (c) Medical interns transcribing medical notes gathered during their rounds

The following lines provide a general description of the activities performed by these three roles:

3.1.1 Nurses

The internal medicine nursing staff include five nurses, supervised by two nurse managers. Some of the activities that the nurse managers do in a work shift are: evaluate the quality of care nurses provide to patients, monitor the administration of medication and gather medical equipment. Generally, they begin their shift by monitoring the patients’ care and notifying each nurse of their pending tasks. After that, they track clinical tests and check medical equipment needed for hospital workers. During this task, they move throughout the hospital interacting with coworkers and taking notes. Finally, they spend the rest of their shift on administrative duties.

3.1.2 Physicians

There are two attending physicians in charge of each area of the hospital per shift, with fifteen to twenty patients per area. The activities performed by physicians during a work shift include: exchange information with colleagues related to events that arose in their absence, conduct exploratory and interrogatory evaluations of patients, update medical notes with tailored treatments and diagnoses, train and evaluate medical interns, discuss with colleagues special clinical cases and participate in surgical procedures.
3.1.3 Medical interns

There are five rotating medical interns in the area. The medical interns are considered physicians-in-training; they provide the most hours of patient care in the unit and are in constant movement. Interns are responsible for the care of five or six patients. One of their main responsibilities is to create clinical histories whenever a new patient arrives in the hospital. They are also responsible for providing care and following-up on patients during their stay in the hospital. Other tasks for which medical interns are responsible have a more collaborative nature, for instance, they participate in ward rounds with attending physicians and in meetings where clinical cases are discussed.

3.1.4 Scenario: A typical day of a medical intern

To illustrate the degree of mobility experienced by hospital workers, we present a scenario that describes a typical working day for one of the medical interns observed. Figure 4 depicts the mobility described in the scenario:

![Figure 4: Mobility of a medical intern during a typical working day](image)

The medical interns meet at 7 am with the physician in charge of the area at the internal medicine office, where they briefly discuss the night’s events described by the intern who was working on the night shift. After the discussion, the interns gather the information related to the patients assigned to them and place it in each patient’s bedroom. They walk down to the laboratory to gather the laboratory results of the patients, and attach them to the medical record. Later, the medical interns meet at the internal medicine office and for one or two hours, they listen to a colleague’s assessment of a particular medical issue or interesting clinical case. After that, they go to the bed wards where along with the physician they conduct the ward round. During this activity they discuss each patient’s clinical case consulting the patient’s medical record and laboratory tests. Finally, once the medical intern has finished the round, which occasionally lasts until 1-2 pm, the rest of the shift is spent mostly doing paperwork in the internal medicine office.

3.2 Data collection

The workplace study started with an observational study conducted for five weeks, where medical workers were closely observed and interviewed by a couple of researchers. Each subject was shadowed for two complete working shifts as indicated in table 1. Our goal was to have a good sample of behaviors and capture the whole experience that those workers face as they conduct their work. The time of each action
was recorded on paper as it occurred, annotating details with respect to the nature of the actions, artifacts used, content of conversations, and physical location of individuals. All time stamps were recorded to the second with as much precision as it was possible. As all records were done by hand at the field site, they were later transcribed and integrated into observation reports to facilitate its analysis and the computation of statistics.

<table>
<thead>
<tr>
<th>Subjects</th>
<th>Work shifts observed</th>
<th>Average hours observed per shift (s.d.)</th>
<th>Total time of observation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Head nurse 1</td>
<td>Afternoon, Afternoon</td>
<td>6:18:00 (0:35:21)</td>
<td>12:36:00</td>
</tr>
<tr>
<td>Head nurse 2</td>
<td>Morning, Morning</td>
<td>7:41:11 (0:12:59)</td>
<td>15:22:21</td>
</tr>
<tr>
<td>Medical intern 1</td>
<td>Morning, Afternoon</td>
<td>6:24:30 (0:33:14)</td>
<td>12:49:00</td>
</tr>
<tr>
<td>Physician 1</td>
<td>Morning, Morning</td>
<td>5:34:23 (0:40:44)</td>
<td>11:08:46</td>
</tr>
</tbody>
</table>

The total time of detailed observation was about 74 hours and 6 minutes, with an average time of observation per subject of 12 hours and 21 minutes. To enhance our understanding of their practices and to clarify issues, we conducted one hour interviews with each subject after the period of observation.

3.3 Data analysis

To understand the medical behaviors experienced by those observed, we conducted an extensive qualitative analysis of the data collected. The particular qualitative approach we followed was inspired by the techniques to derive grounded theory originally proposed by Straus and Corbin, 1998. These techniques have been widely used in a variety of research studies focused on the study of information systems usage, distributed collaboration, and medical informatics, among others (Gonzalez and Mark, 2004; Orlikowski, 1993; Reddy et al., 2001). For our particular case, the qualitative technique of analysis involved continuous sense making of the information collected including interview transcripts, personal notes and documents. As a result of this analysis, we developed a coding scheme that describes the activities performed by hospital workers. This coding scheme was cross analyzed during discussions among the researchers to validate and refine their categories and properties.

A quantitative analysis was conducted to estimate the time hospital workers spend in different activities; the distance they move, the places they move to and the reason for moving there; the people they collaborate most often with and the artifacts they use in support of their work. Thus, data were transcribed into spreadsheets with columns for time stamps, description of actions, subjects involved in the actions, artifacts used, physical location, etc. We used other columns in the spreadsheet to annotate the codes, so it was relatively easy to make changes as the coding scheme was refined. We estimated the total time per day, the average number of segments and the mean time of segments observed for each subject.

The results obtained from the analysis enabled us to understand the medical behaviors exhibited by hospital staff (from a qualitative perspective), and to quantify the time hospital staff invested in those behaviors (from a quantitative perspective). Furthermore, our analysis let us measure the mobility experienced by hospital workers and the frequency of the interactions carried out with artifacts and colleagues. Based on
this data, we could characterize the medical phenomena with the aim of providing a
ground base that could provide insights for the design of mobile and pervasive
technology. In the next section, we discuss these results and their implications.

4 Understanding work mobility in hospitals

This section presents the results of the study showing the mobile nature of hospital
work, the frequency and percentage of the time invested in activities performed by
hospital workers, and the interactions with artifacts and colleagues.

4.1 Characterizing and quantifying activities performed by hospital workers

Here we present the results of our qualitative and quantitative analysis to understand
the medical behaviors experienced by those individuals observed.

4.1.1 Activities performed by hospital workers

From our qualitative analysis, basic fundamental activities emerged. These are the
meaningful behaviors that could be extracted from the data collected through the
qualitative analysis. We observed that these behaviors could take place either at a “base
location” (that is the main place where the subjects spend most of their time) or “on the
move” (while outside of it). For nurses, the base locations were either the nurse
pavilion or the nurse office. For medical interns and physicians it referred to a common
office shared with other personnel of the department. These basic behaviors are defined
in the following lines:

A. Information management
Refers to the activities performed by hospital workers that are focused on capturing
and consulting the information relevant to their work; gathering information;
monitoring the status and availability of information such as laboratory tests’ results
and; formalizing the notes taken on the move to create medical documentation.

B. Coordination
Involves activities related to personnel management and supervision of the quality of
care that hospital staff provide to patients. We classify these activities as follows:
distributing personnel, supervising quality of care, coordinating and notifying pending
tasks.

C. Clinical case assessment
Refers to the activities conducted by hospital staff to assess the health condition of a
patient. Some of these activities are: examination of clinical evidence, discussion of
patient diagnoses, consulting reference material, decision making, and writing
diagnoses.

D. Patient care
Involves the activities that hospital staff carry out to provide primary care for patients.
It involves different tasks such as: health assessment, patient examination, patient
hygiene, vital signs monitoring, medication administration, and patient advising.

E. Tracking
Refers to the activities hospital staff do to locate colleagues or artifacts. These
activities include: tracking people, medical equipment, and documents.

F. Patient census

Includes the activities involved in monitoring the status of services, identifying pending tasks related to patient care and checking the availability of resources. Patient census involves tasks such as: shift connection, when staff from different shifts exchange information related to previous events and documents, and, preparing the area census, when staff monitor the availability of resources, such as beds, medication or special equipment.

G. Classes and certification

Refers to activities related to the training of hospital staff. These activities involve assisting to a class session where clinical cases are discussed, or to meetings where new techniques to improve hospital staff skills are presented.

4.1.2 Hospital workers’ activities

We measured the time hospital workers spent in the activities established in the qualitative analysis. As described in Table 2, most of the time is spent in information management (22.71%), followed by coordination (17.08%), clinical case assessment (15.35%) and patient care (12.6%). Upfront, it is clear that an important part of the work of those observed is focused on activities that have a secondary goal of caring for patients such as information management, coordination, tracking, and preparing the patient census. As Table 2 shows, the time nurses and medical interns spend in these activities surpasses the time they invest providing clinical care. This is in contrast with physicians, who spend more time evaluating clinical cases and with patients. We observed that nurses and medical interns spend considerable time “setting up” the environment, for physicians to focus on their main goal: providing clinical care.

<table>
<thead>
<tr>
<th>Hospital workers activities (Time per day per subject)</th>
<th>Head nurses</th>
<th>Medical interns</th>
<th>Physicians</th>
<th>Average of total time per day per subject</th>
<th>Percent average (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time %</td>
<td>Time %</td>
<td>Time %</td>
<td>Time %</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Information management</td>
<td>1:34:06</td>
<td>22.43</td>
<td>1:54:10</td>
<td>29.70</td>
<td>0:49:12</td>
</tr>
<tr>
<td>Coordination</td>
<td>2:19:15</td>
<td>33.19</td>
<td>0:29:01</td>
<td>7.55</td>
<td>0:32:20</td>
</tr>
<tr>
<td>Clinical case assessment</td>
<td>0:03:15</td>
<td>0.78</td>
<td>0:59:32</td>
<td>15.49</td>
<td>1:31:54</td>
</tr>
<tr>
<td>Patient care</td>
<td>0:30:43</td>
<td>7.32</td>
<td>0:55:45</td>
<td>14.50</td>
<td>0:49:07</td>
</tr>
<tr>
<td>Personal activities</td>
<td>0:34:59</td>
<td>8.34</td>
<td>0:37:30</td>
<td>9.76</td>
<td>0:19:36</td>
</tr>
<tr>
<td>Others</td>
<td>0:23:33</td>
<td>10.14</td>
<td>0:00:00</td>
<td>0.00</td>
<td>0:35:54</td>
</tr>
<tr>
<td>Tracking</td>
<td>0:18:28</td>
<td>4.40</td>
<td>0:37:05</td>
<td>9.65</td>
<td>0:05:58</td>
</tr>
<tr>
<td>Patient census</td>
<td>0:21:46</td>
<td>5.19</td>
<td>0:19:47</td>
<td>5.15</td>
<td>0:16:54</td>
</tr>
<tr>
<td>Classes and certification</td>
<td>0:22:23</td>
<td>5.33</td>
<td>0:23:41</td>
<td>6.16</td>
<td>0:03:56</td>
</tr>
<tr>
<td>Use of support equipment</td>
<td>0:12:08</td>
<td>2.89</td>
<td>0:07:52</td>
<td>2.05</td>
<td>0:03:00</td>
</tr>
<tr>
<td>All</td>
<td>6:59:35</td>
<td>100</td>
<td>6:24:24</td>
<td>100</td>
<td>5:07:32</td>
</tr>
</tbody>
</table>

Hospital staff spend a considerable amount of time managing information during their work shift; therefore, we decided to look closer at the different tasks included in this classification. Table 3 shows the detail of time and percentage that our subjects spent doing these tasks. Information capture represents 13.43% of the information management activities. Information might need to be captured to create or maintain
artifacts that serve as medical documentation (e.g. a medical record of a patient). On the other hand, information can be captured to support coordination between hospital workers (e.g. a table listing schedules for different nurses). Another significant task is monitoring information status which takes on average 4.95% of the information management activities. Hospital staff monitor information to be aware of the status of requested medical tests, clinical histories or medical notes. Gathering information represents 2.74% of the time spent on information management activities. Hospital staff perform this task to engage in the compilation or search of information artifacts. We observed that the information searched might be in paper or digital form. Information consultation takes on average 1.29% of the time. Information might need to be consulted to support decision-making, synchronize information or elaborate reports. Finally, formalizing information represents 0.27% of the information management activities. This task was carried out when individuals formalize medical information in documents that was originally captured on a piece of paper or in their notebook, for instance, during ward rounds.

Table 2 Time and percentages of the activities related to information management

<table>
<thead>
<tr>
<th>Information management activities</th>
<th>Total time per day per subject</th>
<th>Percentage of time/day per subject (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Information capture</td>
<td>0:50:46</td>
<td>13.43</td>
</tr>
<tr>
<td>Monitoring information state</td>
<td>0:10:22</td>
<td>4.95</td>
</tr>
<tr>
<td>Gathering information</td>
<td>0:18:45</td>
<td>2.74</td>
</tr>
<tr>
<td>Information consultation</td>
<td>0:04:54</td>
<td>1.29</td>
</tr>
<tr>
<td>Formalizing information</td>
<td>0:01:02</td>
<td>0.27</td>
</tr>
<tr>
<td>All</td>
<td>1:25:49</td>
<td>22.71</td>
</tr>
</tbody>
</table>

4.2 Mobile nature of work

We first identified those operation centers, within the information space, that were visited by the subjects during the period of observation. We called operation centers to the physical places where hospital workers conducted their work, places such as laboratories, hospital departments, nurse’s areas, trauma areas, etc. We classified them in 5 operation centers as indicated in table 2. We found that each subject moved around an average of 15.5 (s.d. 5.5) different operation centers per day during the time of observation.

A second analysis was directed towards revealing the weight that mobility plays in the work practices of those observed. We found that individuals spent, on average, 59.92% of their time in their base location while the rest is spent at others’ operation centers (40.08%). Upfront it is clear that an important part of the work of those observed is conducted outside their bases. Nurses, physicians, and medical interns have to care for patients in different rooms and consult information in other areas. Also, we found out that medical interns and physicians spend a significant part of their time in the hallway, 7.56% and 9.73% respectively. We observed that when those subjects where in the hallway, other staff often contacted them to ask for specific information (laboratory results, administrative forms, reference material, etc.) or issues related to patient assessment. Also, the physicians and medical interns choose the hallway to discuss the health condition of a patient with colleagues or relatives. Thus, the hallway is used as an “availability space” where many discussions and information exchanges take place. However, it is also important to understand that, although neither nurses nor medical interns and physicians are assigned to individual work areas (e.g. desks), they
still identify and stay at particular locations for a significant proportion of their time. Table 4 shows the percentage and amount of time that our subjects spent in each operation center.

### Table 3 Time spent by hospital workers in each operation center

<table>
<thead>
<tr>
<th>Location (Time per day per subject)</th>
<th>Head nurses</th>
<th>Medical interns</th>
<th>Physicians</th>
<th>Average of total time per day per subject</th>
<th>Percent average (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Time</td>
<td>%</td>
<td>Time</td>
<td>%</td>
<td>Time</td>
</tr>
<tr>
<td>&quot;in their base&quot;</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&quot;on the move&quot;</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bed wards</td>
<td>0:55:45</td>
<td>13.45</td>
<td>1:56:02</td>
<td>30.97</td>
<td>1:44:42</td>
</tr>
<tr>
<td>Hallway</td>
<td>0:06:46</td>
<td>1.64</td>
<td>0:30:04</td>
<td>7.56</td>
<td>0:29:53</td>
</tr>
<tr>
<td>Personal area</td>
<td>0:01:09</td>
<td>0.28</td>
<td>0:12:57</td>
<td>3.49</td>
<td>0:13:12</td>
</tr>
<tr>
<td>Warehouse/special area</td>
<td>0:37:30</td>
<td>9.09</td>
<td>0:06:54</td>
<td>1.86</td>
<td>0:11:52</td>
</tr>
<tr>
<td>All</td>
<td>6:59:35</td>
<td>100%</td>
<td>6:24:24</td>
<td>100%</td>
<td>5:07:32</td>
</tr>
</tbody>
</table>

An additional analysis of our data was focused on the distance covered by our subjects during their work shift. This information was used to complement our understanding of their mobility. By measuring and computing the distance walked among operation centers, we found that on average our subjects covered around one (1) kilometer during their work shifts (mean 1076 meters - s.d. 593 meters). Looking at the individuals’ episodes of displacement, we found that every time a subject had to move from one place to another (except for short distance within the same operation center), on average the subject moves a considerable distance (18.75 meters – s.d. 13.42 meters). This is an indication of the high mobility experienced by hospital staff while conducting their work.

### 4.3 Interactions with people and artifacts

We conducted further analysis to determine the percentage of time that people interact with their colleagues. As indicated in Table 5, both medical interns and nurses spend most of their time interacting with subjects of the same role. For example, medical interns spend 34.42% of their work shift interacting with other medical interns. Similarly, head nurses spend 44.13% of their time interacting with other nurses. In contrast, physicians spend 62.64% of their work shift interacting with medical interns, which is more than half the time they spend at the hospital, and 43.38% interacting with other physicians. The sum of the percentage of time spend with other people shown in Table 5 is greater than 100% because they might be at the same time with people with different roles. For instance, during the ward rounds a medical intern is both with a physician and other medical interns.

---

2 This analysis was conducted with only four of our subjects covering the night shifts when subjects in general have less mobility.
Table 4 Time spent with other people in the hospital

<table>
<thead>
<tr>
<th>Role</th>
<th>Head nurses</th>
<th>Medical interns</th>
<th>Physicians</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time (per day per subject)</td>
<td>Time</td>
<td>%</td>
<td>Time</td>
</tr>
<tr>
<td>Medical Intern</td>
<td>2:22:08</td>
<td>33.87</td>
<td>2:12:20</td>
</tr>
<tr>
<td>Physician</td>
<td>1:03:52</td>
<td>15.22</td>
<td>1:44:26</td>
</tr>
<tr>
<td>Nurse</td>
<td>3:05:09</td>
<td>44.13</td>
<td>2:01:47</td>
</tr>
<tr>
<td>Patients</td>
<td>0:40:47</td>
<td>9.72</td>
<td>0:45:45</td>
</tr>
<tr>
<td>Relatives</td>
<td>0:30:33</td>
<td>7.28</td>
<td>0:04:47</td>
</tr>
<tr>
<td>Specialist</td>
<td>0:03:12</td>
<td>0.76</td>
<td>0:10:05</td>
</tr>
<tr>
<td>Administrative</td>
<td>0:03:14</td>
<td>0.77</td>
<td>0:05:16</td>
</tr>
<tr>
<td>All</td>
<td>7:48:55</td>
<td>111.7</td>
<td>7:04:24</td>
</tr>
</tbody>
</table>

We also measured the amount of time that subjects spend interacting with information artifacts. As indicated in Table 6, the artifact most often used is the medical record, used on average in 15.97% of the subjects’ work shift. As we expected, the subjects that use this artifact most of the time are the physicians with 27.58% followed by the medical interns with 15.43% per work shift. Second in relevance are the administrative forms, with an average of 13.62% per day, per subject. As our results indicated, nurses spend 21.45% of their work shift writing or consulting administrative forms. This can be partially explained by the fact that the nurses we observed are head nurses, and perform many administrative tasks, in contrast with operative nurses who spend more time on patient care. Third in relevance are the personal notes with an average of 10.40% per day, per subject. Personal notes are more often used by medical interns with 21.17% of their work shift, followed by nurses with 8.74%. Both medical interns and nurses need to write informal notes that they might later integrate into other documents, such as medical notes or administrative forms.

Table 5 Time spent interacting with information artifacts

<table>
<thead>
<tr>
<th>Artifact</th>
<th>Head nurses</th>
<th>Medical interns</th>
<th>Physicians</th>
<th>Average of total time per day per subject</th>
<th>Percent average (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time (per day per subject)</td>
<td>Time</td>
<td>%</td>
<td>Time</td>
<td>%</td>
<td>Time</td>
</tr>
<tr>
<td>Medical record</td>
<td>0:20:30</td>
<td>4.89</td>
<td>0:59:20</td>
<td>15.43</td>
<td>1:24:50</td>
</tr>
<tr>
<td>Administrative forms</td>
<td>1:30:01</td>
<td>21.45</td>
<td>0:14:04</td>
<td>3.66</td>
<td>0:48:24</td>
</tr>
<tr>
<td>Personal notes</td>
<td>0:36:41</td>
<td>8.74</td>
<td>1:21:23</td>
<td>21.17</td>
<td>0:03:56</td>
</tr>
<tr>
<td>Computing equipment</td>
<td>0:03:00</td>
<td>0.71</td>
<td>1:08:41</td>
<td>17.87</td>
<td>0:33:29</td>
</tr>
<tr>
<td>Study results</td>
<td>0:05:44</td>
<td>1.37</td>
<td>0:01:17</td>
<td>0.33</td>
<td>0:33:34</td>
</tr>
<tr>
<td>Communication equipment</td>
<td>0:17:27</td>
<td>4.16</td>
<td>0:02:25</td>
<td>0.63</td>
<td>0:06:59</td>
</tr>
<tr>
<td>Reference material</td>
<td>0:05:38</td>
<td>1.34</td>
<td>0:02:15</td>
<td>0.59</td>
<td>0:07:51</td>
</tr>
<tr>
<td>Nursing board</td>
<td>0:10:41</td>
<td>2.55</td>
<td>0:02:34</td>
<td>0.67</td>
<td>0:00:36</td>
</tr>
<tr>
<td>Patient board</td>
<td>0:04:10</td>
<td>0.99</td>
<td>0:01:14</td>
<td>0.32</td>
<td>0:05:04</td>
</tr>
<tr>
<td>Measurement equipment</td>
<td>0:00:00</td>
<td>0.00</td>
<td>0:05:15</td>
<td>1.37</td>
<td>0:00:34</td>
</tr>
<tr>
<td>Display equipment</td>
<td>0:00:41</td>
<td>0.16</td>
<td>0:02:13</td>
<td>1.00</td>
<td>0:00:00</td>
</tr>
<tr>
<td>Nurse sheet</td>
<td>0:01:02</td>
<td>0.25</td>
<td>0:01:33</td>
<td>0.40</td>
<td>0:00:45</td>
</tr>
<tr>
<td>All</td>
<td>3:15:36</td>
<td>46.62</td>
<td>4:02:13</td>
<td>63.44</td>
<td>3:46:02</td>
</tr>
</tbody>
</table>
4.4 Limitation of the study

Our study is limited by the relatively low number of subjects and the hospital areas that we observed. We observed six hospital workers for two complete working shifts, and with this sample it is not possible to derive findings that can be statistically significant and extend across larger populations. The activities performed by hospital staff are in general the same in other hospitals in Mexico and other countries, so we believe that the general findings that we obtained are not restricted to this hospital in particular. However, we want to clarify that our efforts centred on acquiring a vast and detailed understanding of the practices of a few individuals across a varied set of circumstances. Therefore, the significance of our results lies in the qualitative nature of the inquiry and the analysis process that we conducted. On the other hand, our study took place at a hospital where information technology infrastructure is limited. Paper documentation dominates most work practices. However, our effort centered on understanding the mobility that hospital workers experienced and those basic processes around the management of information, which emerge independently of computer technology. Getting that foundation, we have good conditions to envision novel forms of automation.

5 Implications for the design and deployment of pervasive computing technology in hospitals

In this section we discuss how the findings of this study can be applied to the design of pervasive technology for hospitals; assessing the feasibility and appropriateness of the technological approaches of pervasive computing discussed in section 2 and revealing new unseen opportunities for this field.

5.1 Transferring information between heterogeneous devices

Even tough it is clear that hospital staff spend as much as half of their working shifts on the move; they do spend a considerable amount of time at what we have referred to as their base location. They need to do this in order to fill in administrative forms, write medical notes or analyze medical documentation. Mobile computing devices, such as PDAs, are not appropriate for many of these tasks, such as writing relatively long documents or reading a medical paper. Thus, the need to provide the environment with heterogeneous computing devices, ranging from handheld computers that can be used to capture and access limited amounts of information (due to limited screen size and text entry capabilities), to desktop computers that can be used at fixed sites for longer periods of time, and finally, semi-public displays located at convenient places, that can be used to share and discuss information with colleagues.

Information transfer between these devices should be seamless, to not interrupt the natural execution of the task at hand. For instance, medical interns currently take notes on paper, or occasionally with a PDA while in ward rounds. They later use this, and additional information, to write a medical note to be sent to the physician who will review it and sign it.

5.2 Support for data capture: Integration of the digital and physical domains

Our data shows that hospital staff spend 13.43% of their time capturing information. This represents by far the most time consuming activity related to the management of information. Although an essential part of hospital work, information capture is often
regarded by our subjects as a necessary evil. One medical intern expressed that in the following way: “we came to the hospital to learn how we can help patients and we learn how to be secretaries”. Our observations indicate that information capture is not just a tedious task, but also one where the original information is obtained while being mobile. Much of the information is captured at the bedside, and consequently tools such as clipboards and pieces of paper are used to take notes. The value of being flexible, and easily transportable, makes of paper a technology that is difficult to defeat with handheld computers (PDA or tablet computers) for the purposes of data capture. However, as people demand flexibility in their notes, paper is often used, and then their notes have to be transcribed afterwards, which results in the frustration expressed by our subjects. Having a computer at the place where those notes are transcribed will not be of much help to ease the challenges of information capture. Somehow, technologies have to support the capture of data when it is being generated.

We argue that to be effective for data capture, a pervasive computing hospital environment has to bridge the gap between the physical and digital worlds, taking the best from each one, and creating innovative solutions. An approach that bridges the gap that we are currently exploring is the development of capturing systems using digital pens. In this solution, the digital pen, which includes a tiny digital camera inside it, is used as a capture device in combination with special paper crafted with a pattern that makes it possible to read what is written. Using digital pen technology, hospital workers can keep using a flexible annotation scheme and paper, yet transfer that information directly to the hospital information systems through the Bluetooth transmitters embedded in the digital pen.

5.3 Working while on the move

Physicians spend almost 10% of their time in hallways. They are there not only to move from one operation center to another, but actually they have meaningful encounters and work while in the hallway. An important reason for this is that other hospital workers and patients' relatives often see their presence in hallways as an opportunity to interact with them. These opportunistic interactions are used among other things to hand them a form to sign, ask about the patients’ health, or discuss a diagnosis. Many of these interactions involve the exchange of documents and/or their analysis. Research in the area of Computer Support Cooperative Work (CSCW) has been conducted towards supporting this type of interaction in office environments through computer-mediated communication. This work has focused on enabling this type of encounters without the parties being physically co-located, by providing awareness of the presence of colleagues and mechanisms for them to communicate remotely.

These solutions are clearly not appropriate for a hospital environment, where according to our data; workers spend only a fraction of their work shift in front of a computer, and more than twice this amount of time away from their base location. Indeed, what is required is support for impromptu face-to-face encounters. We envision this support with a set of services on their handheld computers. These services include the ability to detect the presence of other PDAs in the vicinity; being able to exchange documents with these devices; synchronize the views of the handheld computes of nearby users with whom they are interacting; and being able to remotely operate and view other computer equipment, such as their own desktop computer.
5.4 Inferring the user’s primary activity in support for context-aware computing

The data collected for this study is at such level of detail, that it can be used to train pattern recognition algorithms to infer contextual information that an application can use to adapt itself to the user. In particular, one might be able to deduce the user’s primary activity from evidence directly collected from sensors, such as: the user’s current location, the time of day, and the presence of colleagues, documents or equipment.

Although one can infer that a physician is in a ward round from being in a patient room, with medical interns at 10am, the use of data from this and similar studies could be used to statistically estimate the likelihood of the doctor actually being in a ward round, or doing other activities. Once the application has strong evidence of the users’ primary activity, it could adapt itself by displaying information relevant to the task at hand, filter incoming messages, or notify colleagues of the user’s activity.

6 Conclusions

We present the results of an observational workplace study conducted in a hospital, aimed at revealing the time hospital workers spend in different activities; the distance they move, the places they move to and the reason they move; the people they collaborate with most often, and the artifacts they use in support of their work. The results aim to contribute towards an understanding of how hospital workers’ activities can be improved by the introduction of mobile and ubiquitous computing technology.

The results of the study indicate that hospital staff spend 50-75% of their time at a base location, which varies depending on their role. This is significant for the design of mobile computing support, since it indicates a need to seamlessly integrate handheld devices with stationary computers that are more appropriate for certain tasks. Mobility results also indicate that physicians spend a considerable amount of time in hallways where they interact with colleagues to discuss current issues. Support for these interactions could include services on the handheld to exchange documents and share the display of the PDA. Data capture is one of the activities in which nurses and medical interns spend a considerable amount of time. They consider this task as being secondary to their primary motivation for their work, namely, patient care. Yet data capture is an essential part of hospital work. Ubiquitous computing technology that can facilitate data capture by integrating the physical and digital domains could reduce this workload.

The results of this study can also serve as a baseline to evaluate the role of technology on altering patterns of mobility and information interaction. Conducting a similar study once the technology is introduced in the hospital could help us measure the extent to which mobile and pervasive technology affects mobility and the amount of time spent performing different activities. We plan to conduct such a study as we work towards the pervasive hospital environment we have envisioned.

References


