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CAMMD: Context-Aware Mobile Medical Devices

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Abstract: Telemedicine applications on a medical practitioner's mobile device should be context-aware. This can vastly improve the effectiveness of mobile applications and is a step towards realising the vision of a ubiquitous telemedicine environment. The nomadic nature of a medical practitioner emphasises location, activity and time as key context-aware elements. An intelligent middleware is needed to effectively interpret and exploit these contextual elements. This paper proposes an agent-based architectural solution called Context-Aware Mobile Medical Devices (CAMMD). This framework can proactively communicate patient records to a portable device based upon the active context of its medical practitioner. An expert system is utilised to cross-reference the context-aware data of location and time against a practitioner's work schedule. This proactive distribution of medical data enhances the usability and portability of mobile medical devices. The proposed methodology alleviates constraints on memory storage and enhances user interaction with the handheld device. The framework also improves utilisation of network bandwidth resources. An experimental prototype is presented highlighting the potential of this approach.

Keywords: Telemedicine, Mobile Devices, Context-Aware Computing, Agent Technology
Categories: H.3.0, H.3.4, H.4.3, I.2.1

1 Introduction

Portable medical devices can provide nomadic practitioners with efficient access to patient records at the point of care. The storage and visual interface of a portable device affects handheld analysis of these medical records. These delimiting factors combined with an intermittent wireless network connection can lead to an unsatisfactory user experience. These issues can be resolved by allowing portable devices to sense and interpret their contextual environment.

A context-aware mobile medical device can proactively assess its environment. The information gathered from this assessment can be interpreted to determine whether data management operations should be applied to the handheld device. This approach anticipates a medical practitioner's specific data requirements. Essentially, relevant patient records are proactively transmitted to a handheld device only when they are required.

The medical data to be propagated is determined using an informed decision-making process that evaluates the contextual environment of the handheld device. This methodology helps alleviate existing problems of information overload and low bandwidth. The intelligent data management framework enhances the usability and portability of a handheld device. Additionally, the timely deployment of relevant medical records helps to eliminate handheld storage and visual interface constraints. These improvements can lead to increased productivity levels for medical practitioners and help to increase the accuracy of their patient diagnosis.

A support infrastructure capable of capturing, communicating and interpreting real-time contextual information is necessary for the successful deployment of context-aware handheld devices. This paper proposes an agent-based architectural solution called CAMMD[1]. Agent technology provides a sophisticated middleware capable of eloquently representing and communicating context-aware information. Agents are well-suited to handheld telemedicine environments as they are efficient in their use of bandwidth and are capable of dealing with intermittent network connections. An agent framework is also effective in representing and working towards the interests and preferences of a healthcare professional.

The nomadic nature of a medical practitioner emphasises location, time and activity as key context aware elements. These real-time data elements must be intelligently interpreted to inform the decision-making process within the agent framework. CAMMD utilises an expert system to determine whether data management operations are required for a handheld device. This rule-based system processes the raw ingredients of time and location of the handheld. These contextual elements are then cross-referenced with the work activity of the handheld user to determine whether data management operations are necessary.

An examination of related work is presented in section two. In section three, an overview of the CAMMD framework is outlined. This section details the agent-based architectural framework and highlights the technologies employed to realise the overall system. Section four depicts an experimental prototype and an analysis of performance results. Finally, conclusions are presented in section five.

2 Related Work

Handheld devices enable healthcare professionals to provide greater levels of patient care. They are a key component in realising the future telemedicine vision of ubiquitous healthcare. There have been a number of research efforts investigating potential benefits and possible strategies for deploying portable devices within a medical environment. The major focus of this work has been an effort to enable medical professionals access, manipulate and analyse patient records whilst on the move.

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[1] Context-Aware Mobile Medical Devices

The benefits of providing wireless handheld access to clinical patient records have been recognised [Ancona, 01]. This work compared an electronic-based record system accessible on portable computers to a traditional paper-based system. The study showed electronic records provided a clear improvement in the productivity of healthcare professionals in comparison with the conventional paper-based system. The potential for minimising errors through utilising the wireless-based system was also recognised.

A web-based telemedicine architecture facilitating wireless access to electronic patient records on a portable device has been proposed [Lamberti, 02]. This approach utilises Java, XML and XSL technologies. The web browser of a mobile device is incorporated as the visual interface. The inherent benefit of using the internet as a communication medium is its ability to operate independently of the client hardware/software device architecture.

The ability to access images of patient scans everywhere and anytime on mobile hardware has also been investigated. This type of wireless application was identified as beneficial for medical practitioners when performing their routine diagnostics [Kroll, 02]. This feasibility study examined applications developed for viewing and analysing DICOM image and waveform objects on handheld devices. Their conclusions recognised the importance of developing handheld applications that prioritised intelligent interaction. This approach helps minimise drawbacks imposed by the physical constraints of a mobile device.

Context-aware computing is recognised as a key element for enabling intelligent handheld devices in healthcare environments. The goal of context-aware computing is to acquire and utilise information regarding the context of a device and to provide services that are appropriate to the particular setting [Bardram, 04].

The nomadic nature of medical professionals within healthcare environments recognises location as a primary element of context-aware computing. This contextual element has been utilised to deliver patient records to handheld devices based upon the location of medical staff [Rodriguez, 04]. Their work recognises the importance of enabling intelligent handheld access to electronic medical records. This enhances device usability and improves the user experience. Their approach is closely related to our research.

A fundamental difference within our approach is the increased emphasis placed upon the need to intelligently interpret the contextual data elements of a handheld device. The expert system employed within our methodology allows for a comprehensive analysis of these data elements. This enhances decision-making ability and enables the framework to deliver more appropriate and proactive support to users of handheld devices. An additional consequence of this sophisticated support infrastructure is its ability to acutely manage physical device and network resources.

3 CAMMD

The CAMMD framework proactively communicates patient records to a portable device based upon the active context of a medical practitioner. Agent technology is employed as the enabling middleware within this data management system. An overview of the agent concept is presented in Section 3.1. The agent infrastructure constructed to enable effective deployment of context-aware mobile medical devices is described in Section 3.2. This section identifies the role of each agent within the framework.

The physical architecture of the CAMMD environment is presented in Section 3.3. This framework is reliant on a mobile medical device being capable of establishing its location. An overview of the technology utilised to achieve location-awareness is described in Section 3.4. The informed decision-making ability within the agent framework is driven by an expert system analysing the contextual environment of each mobile medical device. An outline of this rule-based system is presented in Section 3.5.

3.1 Agent Concept

Agent technology is the enabling middleware utilised by the distributed components within CAMMD. In the context of software engineering, an agent can be defined as [Wooldridge, 97]:

> *"An entity within a computer system environment that is capable of flexible, autonomous actions with the aim of complying with its design objectives"*

A mobile agent adheres to the above definition as well as having the added capability of traversing networks. The field of agent technology is seen as a highly suitable paradigm and inter-communication infrastructure for the analysis and design of mobile telemedicine systems [Della Mea, 01].

This work views agent technology as a vast improvement to the traditional client-server approach for developing complex telemedicine applications. These systems can be defined as communities of interacting entities that aim to support collaboration and resource sharing in a medical environment. This observation is especially prevalent for mobile telemedicine systems which have continuously appearing and disappearing components within their distributed network. An agent embodies characteristics of autonomy and sociality which make the multi-agent paradigm highly appropriate to develop mobile telemedicine systems.

3.2 Agent Infrastructure

The agent-based infrastructure facilitating context-aware mobile medical devices is shown in Figure 1. This diagram highlights paths of intercommunication amongst agents as well as dynamic agent creation. Each agent role was determined using an agent-oriented analysis and design technique [Wooldridge, 99].

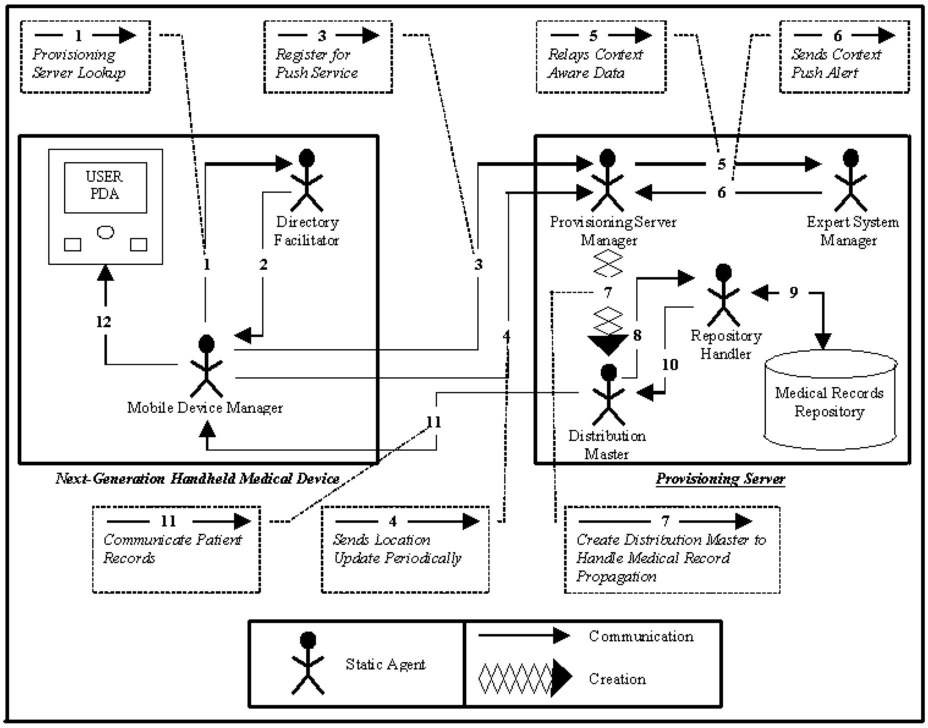

Figure 1: CAMMD Agent Infrastructure

The role of each agent within the CAMMD framework is outlined as follows:

- *Mobile Device Manager*
  This single instance agent is a permanent resident on the mobile medical device and has responsibility for gathering and maintaining information about the physical device and its owner. The agent operates as the main point of contact between the user and medical applications. The agent registers for a medical record provisioning service. The operation of this service is based upon the contextual environment of the handheld device. The agent is also responsible for informing the provisioning server of any changes in the location of the handheld.

- *Directory Facilitator (DF)*
  The Directory Facilitator is responsible for maintaining knowledge about the location and services of each agent within the platform.

- *Provisioning Server Manager*
  This agent is responsible for the provisioning of electronic patient records to handheld medical devices based upon their active context. This agent accepts a request to provide a data management service to a portable device. The Provisioning Server Manager acts upon location updates from medical devices.

These location alerts are triggered as the medical practitioner moves within the hospital. This information is communicated to the Expert System Manager to determine whether data configuration is required for the handheld device. A positive response from this agent will result in the creation of a Distribution Master agent to begin propagation of patient records to the mobile medical device.

- *Expert System Manager*
  The Expert System Manager maintains an interface to a rule-based expert system. This agent is responsible for controlling and interacting with the rule engine. This involves gathering the contextual data elements of a handheld device and communicating these values to the expert system. The decision of the rule engine informs the Expert System Manager whether data management operations are required.

- *Distribution Master*
  This agent is instantiated as needed and is responsible for handling the propagation of patient records to a mobile medical device. This involves efficient inter-communication with the Repository Handler to obtain relevant records from persistent storage. These records are packaged into a medical-based message template and transmitted to the handheld device.

- *Repository Handler*
  The Repository Handler interfaces with a medical database to obtain patient records.

3.3 System Architecture

The CAMMD framework facilitates the proactive communication of patient records to a portable device based upon the active context of its medical practitioner. The system architecture of CAMMD is shown in Figure 2. Java Agent Development Environment (JADE) is incorporated as the active agent platform on the provisioning server and JADE-LEAP is the active agent platform on each handheld medical device.

JADE is a Java-based open source development framework aimed at developing multi-agent systems and applications [Bellifemine, 99]. JADE-LEAP (JADE-Lightweight Extensible Agent Platform) is an agent-based runtime environment that is targeted towards resource constrained mobile embedded devices [Berger, 03]. Both JADE and JADE-LEAP conform to FIPA (Foundation for Intelligent Physical Agents) standards for intelligent agents. FIPA is a standards organization established to promote the development of agent technology [FIPA, 04].

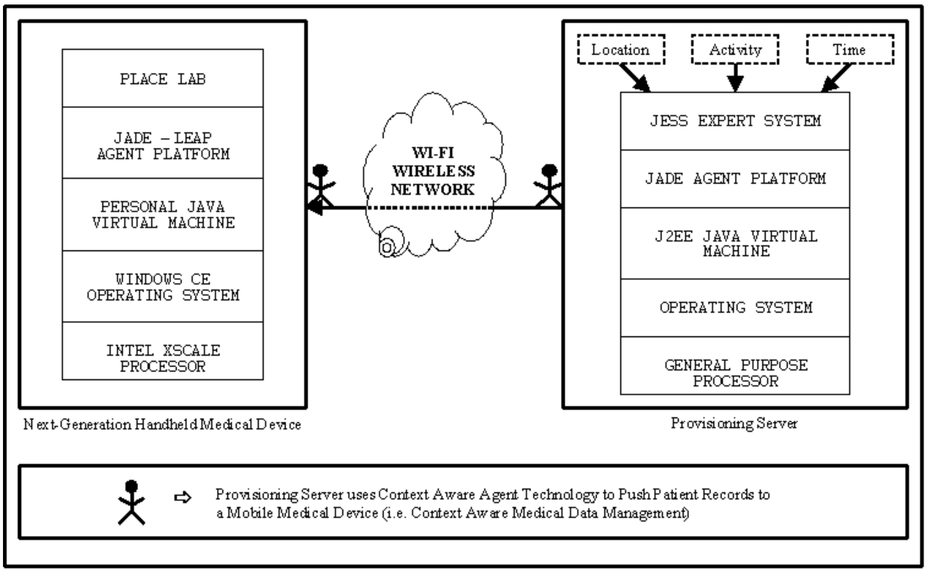

Figure 2: CAMMD System Architecture

3.4 Location System

A contextual element required for successful deployment of the proposed architectural framework is knowledge of the location of the handheld device. This is facilitated within the framework through the incorporation of Place Lab technology within each portable device. This is an open source development project that uses a radio beacon-based approach to location [LaMarca, 05]. An agent executing on a portable device can use the Place Lab component to estimate its geographic position. This is achieved by listening for unique identifiers (i.e. MAC addresses) of Wi-Fi routers. These identifiers are then cross-referenced against a cached database of beacon positions to achieve a location estimate.

3.5 Jess

The deployment strategy to push medical records to a handheld device is reliant upon a rule based expert system. This informs the decision-making process of agents on the provisioning server. Jess is the rule engine and scripting language employed within the framework [Friedman-Hill, 03]. This is a Java-based expert system that can interpret and evaluate the contextual elements of a portable device to recommend data management operations.

The contextual elements required to enable effective configuration management are the location of the handheld device, the time of day, and the activity of the user. The user activity is derived from a predetermined schedule of practitioner appointments with patients.

```
;;Checking For Positive Time Match
(defrule timeChecker1 (ActiveContext (activeStartTime ?activeStartTime))
                      (ActiveContext (activeEndTime ?activeEndTime))
                      (ActiveContext (currentTime ?currentTime))
                      (test (>= ?currentTime ?activeStartTime))
                      (test (<= ?currentTime ?activeEndTime))
                      =>
                      (printout t "
                      TIME_MATCH_FOUND
                      In Rule Base:
                      Current Time is: " ?currentTime "
                      and this is within the appointment
                      start time of: " ?activeStartTime "
                      and the appointment finish time
                      of: " ?activeEndTime "
                      " crlf)
                      (store TimeOutcome TimeOutcomeMatch))
```

Figure 3: A Jess rule which cross-references appointment times with the current time

The contextual elements are examined by the expert system through firing a collection of pre-defined rules. An example rule which cross-references the time aspect of a practitioner's schedule against the current time is shown in Figure 3.

4 Prototype & Performance Results

An experimental prototype has been implemented to evaluate the performance of the CAMMD framework. This prototype facilitates the proactive communication of patient records to a portable device based upon the active context of its medical practitioner. Screenshots of this prototype are shown in Figure 4.

The left screenshot shows the graphical interface displayed to a medical practitioner upon initialisation of the CAMMD application. This screen displays the current time and location of the handheld device. The graphical interface is displaced upon receipt of a push of medical records from the provisioning server. This data management operation is triggered by the active context of the medical practitioner. The propagated data consists of details related to the current practitioner's appointment and any associated patient records as shown in Figure 4(b). The graphical interface displays the location and time specific details related to the appointment and a list of associated patient names. The screenshot shown in Figure 4(c) is generated upon the selection of a patient name from this list. The graphical interface displays the medical records of the selected patient. It includes general patient information and a list of their health diagnostics. The screen also informs the practitioner of any recent medical scans.

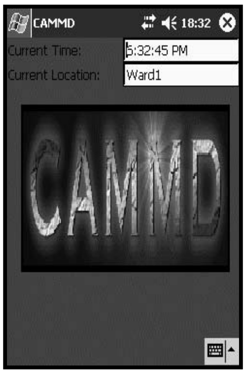

Figure 4(a):
CAMMD Initial Screen

Figure 4(b):
Context Aware Patient List

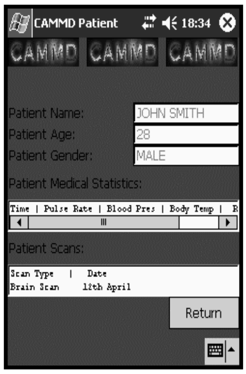

Figure 4(c):
Individual Patient Details

Figure 4: CAMMD Prototype Screenshots

The prototype environment consists of a Dell Axim PDA with a Pocket PC 2003 operating system. Each PDA executes the JADE-LEAP agent platform using a Personal Java virtual machine called Jeode. The provisioning server operates on a high-end Pentium PC running the JADE agent platform. The Jess rule-based expert system resides on the provisioning server. Patient records propagated to handheld medical devices within the hospital are stored in a SQL Server database. A Place Lab software plug-in resides on each handheld device enabling an accurate location estimate to be communicated to the provisioning server. Agents communicate between the distributed components over a Wi-Fi network.

The test case deployment entailed assessing CAMMD handheld devices within a laboratory environment. The testing scenario closely emulates the physical ward layout of Cork University Hospital.

Four individual tests were executed to evaluate the performance of CAMMD and these are outlined in Table 1. Each test was conducted using both the CAMMD framework and a Remote Method Invocation (RMI) medical-based implementation. The tests operated within a simulated environment of ten geographically distributed wards. A timing scenario based upon guidelines for medical practitioner consultations was used as the test-case benchmark [BMA, 04]. This British Medical Association report recommended a minimum of fifteen minutes per patient. The use case scenario randomly distributed twenty-seven patients over ten wards to represent the daily workload of a medical practitioner. The patient to ward distribution is shown in Table 2. A walk-through of the wards was conducted by ten individuals to achieve results for each test case.

The first test examines the storage required by a CAMMD enabled handheld device when applying this use case scenario. Storage costs for the RMI implementation were also obtained. The results of this test case are shown in Figure 5(a).

Type	Test Name	Description
Physical Constraint Test	Handheld Device Storage	CAMMD Determine the storage cost on the handheld device resulting from the propagation of patient records. Remote Method Invocation Determine the storage cost on the handheld device resulting from a retrieval of patient records.
	Network Bandwidth Usage	CAMMD Determine the network bandwidth consumed by a CAMMD handheld device. Remote Method Invocation Determine the network bandwidth consumed by the RMI implementation.
Usability and Interaction Test	Data Transmission Time	CAMMD Determine the time taken to perform a data management operation. Remote Method Invocation Determine the time required for a retrieval of patient records from a provisioning server.
	User Navigation	CAMMD Determine the average user time to navigate to a patient medical record. Remote Method Invocation Determine the average user time to navigate to a patient medical record.

Table 1: Overview of Performance Evaluation Tests

Ward Number	1	2	3	4	5	6	7	8	9	10
Number of Patients	3	2	4	3	2	4	3	3	2	1

Table 2: Patient to Ward Distribution

The data storage on the PDA using the RMI implementation is constant due to the retrieval of every patient record for the medical practitioner at each ward. In comparison, the CAMMD implementation requires on average 80% less storage by retrieving patient records only associated with the practitioner's active context.

The second test examines the network bandwidth usage of a CAMMD enabled handheld device. Bandwidth usage of an RMI enabled device was also obtained. The results of this test case are shown in Figure 5(b). The network usage of the RMI enabled device is again constant and is calculated by determining the cost of invoking a remote retrieval of patient records. In comparison, the bandwidth usage of a CAMMD device fluctuates according to number of patient records transmitted and the frequency of location updates.

For example, test results for Ward 1 showed the bandwidth usage within the RMI implementation to be approximately 1100 bytes. The CAMMD test results for Ward 1 are based upon a series of location updates (right Y-axis) communicated to the provisioning server and the patient records (left Y-axis) propagated to the handheld device. These combined figures show a bandwidth usage of approximately 250 bytes (approx. 190 bytes – patient records, 60 bytes – location updates) highlighting an improvement of over 75% in relation to the RMI implementation.

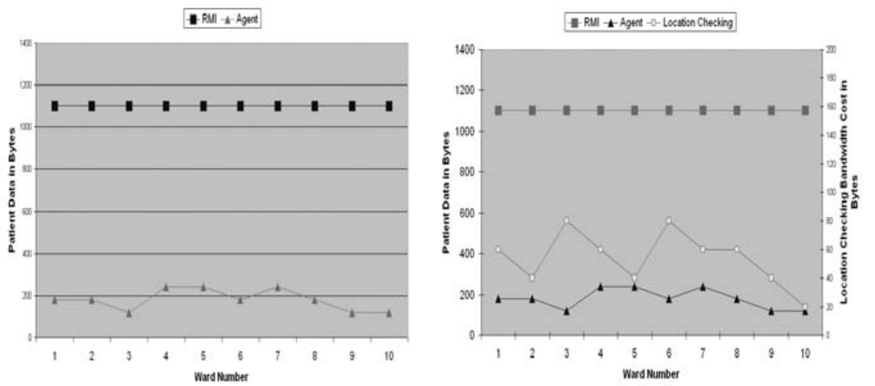

Figure 5(a): Handheld Device Storage

Figure 5(b): Network Bandwidth Usage

Figure 5: Physical Constraint Tests

The medical records are currently of a simple textual nature resulting in low memory requirements. Complex medical records with images of patient scans will show even greater disparity between RMI and CAMMD approaches in network bandwidth usage and handheld device storage requirements. The CAMMD framework clearly optimises the physical constraints of a handheld device and this improves device portability.

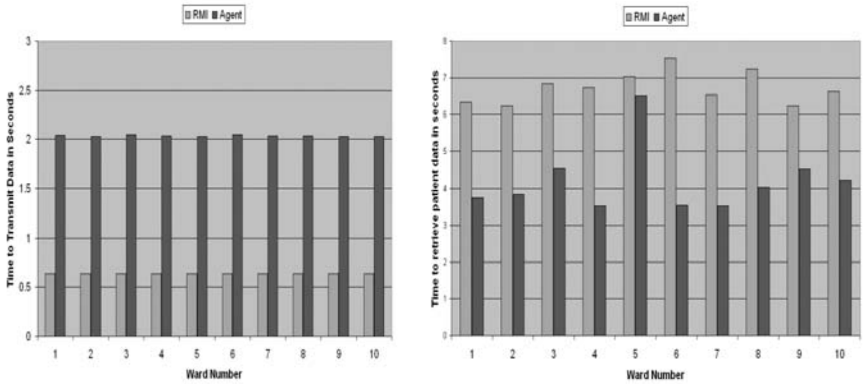

Figure 6(a): Data Transmission Time

Figure 6(b): User Navigation

Figure 6: Usability / Interaction Tests

The third test examines the data transmission time of a CAMMD enabled handheld device. Transmission times of the RMI implementation were also obtained. The results of this test case are shown in Figure 6(a). Time to communicate patient records within the RMI and CAMMD-based prototypes is relatively constant. This is mainly due to the stability and availability of the wireless network. The results show the RMI implementation retrieves medical records on average three times faster than the CAMMD framework. The primary reason for this disparity is the inherent overhead associated with an agent framework.

The fourth test evaluates the average time required by each user to navigate to a specific patient record in each ward. This test case examined the usability of both implementations. The results of this test case are shown in Figure 6(b). The concise nature of the patient records returned to a CAMMD enabled handheld device showed faster navigation times to individual patient records. The navigation time with the RMI-based implementation was on average two seconds slower. The primary cause of this delay is due to the extra time required to locate a specific patient within a larger list. The CAMMD implementation clearly improved user interaction by helping to avoid information overload.

5 Conclusions

Healthcare organisations are increasing their reliance on mobile links to access patient medical records at the point of care. Mobile access to patient records improves the productivity of healthcare professionals and enhances the accuracy of their diagnosis. Handheld analysis of medical records is hindered due to the storage and visual interface constraints of a portable device. These physical constraints affect user interaction with handheld applications. This factor combined with an intermittent wireless connection can jeopardise the vision of a ubiquitous telemedicine environment.

This paper presents the CAMMD framework to deliver context-aware handheld medical devices. The agent-based architectural solution proactively communicates patient records to a portable device based upon the active context of a medical practitioner. This distribution of medical data enhances the usability and portability of mobile medical devices as shown in the usability and interaction tests. The proposed methodology also overcomes handheld device and network issues as shown in the physical constraint tests. The CAMMD framework is a step towards realising the vision of a ubiquitous telemedicine environment.

Acknowledgements

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