Software Development and Evaluation for Remote Control and Audio-Video Communication for a Narcotic Dependency Rehabilitation Tablet Dispenser Based on LAN.

By

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Declaration of Originality

I declare that this thesis to contain no material which has been accepted for a degree or diploma by the University or any other institution, except by way of background information and duly acknowledged in the thesis, and to the best of my knowledge and belief no material previously published or written by another person except where due acknowledgement is made, is included in the text of the thesis.

Signed

.... Aman Bajracharya

ABSTRACT

There are often serious problems with misuse and diversion of narcotic rehabilitation medication when supplied to patients as Take Away Doses (TADs) rather than as a daily dose given under supervision at a pharmacy. Despite this, TADs are often supplied in narcotic rehabilitation programs to help patients live normal lives, promote rehabilitation, improve retention in treatment, reduce congregation at dispensing points and improve access to treatment. Problems arise because TADs are taken unsupervised with no monitoring to ensure that they are taken as prescribed. There is also no "intoxication" assessment of the patients immediately prior to dosing to ensure it is safe for the patient to consume a TAD. There is also no suitable technology currently available to remedy this situation. The University of Tasmania Medical Engineering Research Group is working to develop suitable technology for secure remote storage and delivery of TADs together with remote assessment of patients immediately prior to TAD delivery. The use of this system has been named tele-drug-rehabilitation. This thesis is concerned with the communication and remote dispensing of tablets required for this technology. A new word 'tele-dosing' has been coined for this part.

The tele-drug-rehabilitation system featured video and audio communication between a local (clinician) and remote (patient) PC and the remote control of a tablet dispenser in the remote location. LabVIEW graphical programming was used to develop the communication software, the user interface and the external dispenser control. A laptop was used at the patient site and a desktop at clinician's site both running on Windows XP. A webcam and 3.5mm microphone and headset were used in each side. MJPEG and wav format were used for video and audio respectively. The patient's computer and the clinician's computer were connected through a Local Area Network (LAN). The dispenser was connected to the patient's computer through a serial port. For remote dispensing, the software provides a mechanism to remotely operate the medication dispenser. The tablet dispenser was designed to hold up to five tablets of buprenorphine. Through the system, the clinician interacts with the patient through video and audio and provides supervisory control of the dispenser. This enables assessment of the patient prior to dispensing, activation of the dispenser only after a satisfactory assessment outcome, and monitoring of the dosing process. The concepts and the programs used in developing the system are described.

The system was initially trialed with ten dummy patients using plastic tablets. User feedback was used for continuous improvement of the software and the hardware. Finally, the system was trialed and evaluated with two real patients in a controlled environment. Buprenorphine tablets were used in the trials. The trials were successful.

Each patient as well as the doctor, was given a set of questionnaires to fill out after the experiment. The questions included the quality of video, audio and audio-video combined, the perception of safety, successful dispensing, comparison of the remote monitoring compared to going to the pharmacist, the cost patients are willing to pay for the system and others.

Trials with dummy patients found the compression level and resolution of image frames suitable for the system. MJPEG based video communication was found to be suitable enough for video communication. The user experience of audio communication was also positive. The dispensing of Buprenorphine tablets to real patients was successful and in the correct order in all trials with real patients. Feedback from the real patients was positive indicating the system was usable and functional and they would prefer home dosing with this system in preference to daily pharmacy visits.

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List of Abbreviations

2G	Second Generation
3G	Third Generation
ADC	Analogue to Digital Converter
bps	bits per sec
Bps	Bytes per sec
CCS	Clinic's Central Server
CDMA	Code Division Multiple Access
Codec	Coder and Decoder
CPU	Central Processing Unit
CRLF	Carriage Return followed by a Line Feed
CUI	Client User Interface
DAC	Digital to Analogue Converter
DAMDW	Dynamically adaptive multidisciplinary work station
DAQ	Data Acquisition
DICOM	Digital Imaging and Communications in Medicine
ECG	Electro Cardiogram
EDGE	Enhanced Data Rates for Global Evolution
EEPROM	Electrically Erasable Programmable Read-Only Memory
FDMA	Frequency Division Multiple Access
FDMA	Frequency Division Multiple Access
GPRS	General Packet Radio Service
GSM	Global System for Mobile Communication
HR	Heart Rate
HSDPA	High Speed Downlink Packet Access
IC	Integrated Chips
IIS	Internet Information Server
IP	Internet Protocol
IP	Invasive blood pressure
ISDN	Integrated Services Digital Network
ITU	International Telecommunication Union
JAFMAS	Java-based Agent Framework for Multi agent Systems

JPEG	Joint Photographic Experts Group
JPIP	JPEG2000 interactive protocol based on HTTP
MJPEG	Motion JPEG
MPEG	Moving Picture Experts Group
MMT	Methadone maintenance treatment
NI	National Instruments
NIBP	Non-Invasive Blood Pressure
PPG	Photoplethesmography
Resp	Respiration
RFC	Request for Comments
RMCS	Remote Monitoring and Control System
RTCP	Real Time Control Protocol
RTP	Real-time Transfer Protocol
Std dev	Standard Deviation
SpO2	Oxygen Saturation
SSL	Secure Sockets Layer
TAD	Take Away Dose
TADs	Take Away Doses
TCP	Transmission Control Protocol
TDMA	Time Division Multiple Access
TDMA	Time Division Multiple Access
Temp	Temperature
UDP	User Datagram Protocol
UMTS	Universal Mobile Telecommunications System
VI	Virtual Instrumentation/ Virtual Instruments
VISA	Virtual Instrument Software Architecture
ViCCU	Virtual Critical Care Unit
WAN	Wide Area Network
WML	Wireless Markup Language

1 Introduction

Telemedicine today is significant in improving medical services and making them easily accessible. It now reaches many branches of medicine. Each application of telemedicine is unique depending on the field and types of people it is addressing. This project is about telemedicine applied to home care and deals specifically with telemedicine for monitoring and control of medication consumption in narcotic drug rehabilitation.

The project is within the University of Tasmania (UTAS) Biomedical Engineering group. The group is developing a tele-drug-rehabilitation system for patients undergoing narcotic maintenance treatment, a treatment in which addicted individuals receive daily doses of a substitute narcotic such as Buprenorphine or Methadone. For the purpose of the thesis, tele-drug-rehabilitation is defined as "providing drug rehabilitation services to intended patients using multimedia technologies" and includes remote delivery of narcotic substitute. The tele-drug-rehabilitation system being developed includes three features - remote-operated mobile medicine dispensers for delivery of prescribed medication for use in the narcotic dependency rehabilitation[1], remote assessment before drug delivery[2] and the software to communicate between the two parties – the doctor and the patient - and to control the dispenser remotely[3]. There are currently no existing medication delivery devices or control and communication systems suitable for remote delivery of this type of medication. Although automatic medication dispensers are readily available for home or pharmacy use, none incorporates the features required in this application. Successful trials have been conducted by others using communication methods directly linking medical and pharmacy staff [4, 5] but there is no system that incorporates remote delivery to patients. Specific features required include remote operation of the delivery mechanism, portability, capability to observe the patient and validate the medication type using video, and provision of recording and analysis capabilities.

This thesis focuses on the latter feature mentioned above – "Communication between the two parties – doctor and the patient - and remote control of the medication dispenser". This thesis is a step in enabling home care based tele-drug-rehabilitation. The project implements currently available technologies and develops new concepts for tele-drug-rehabilitation of narcotic dependent patients. Finally, an assessment of the usefulness of the developed communication and the control system has been made in a controlled environment from the patient's as well as the doctor's perspective.

1.1 Statement of Problem

People addicted to opiates are treated by medically supervised prescribed maintenance. There are three parties involved: the doctor who prescribes the medicine and the pharmacist who supervises the treatment and the patient. In Australia, there are two main pharmaceutical options for narcotic maintenance treatment. First option is Methadone, which is available as an oral liquid and given daily and Buprenorphine (brand name Subutex©) which is available as a tablet (0.4 mg, 2 mg, 8 mg) and given daily to 3 times per week. Research has shown that prescription of Buprenorphine results in an improved treatment response for narcotic addicted people[6, 7]. A "dosing supervisor", who is usually the dispensing pharmacist, supervises dosing. However, patients who respond to treatment are gradually introduced to non-supervised doses that they can take away from the dispensing point to be consumed later (for example at work or home). These non-supervised doses are also called Take-Away-Doses (TADs). Figure 1-1 shows the current medical practise. The non-supervised doses or TADs are provided to patients at the pharmacy for use on other days, thereby reducing the number of attendances required at the delivery point. TADs can be valuable to reward treatment progress and improve the quality of life of patients.

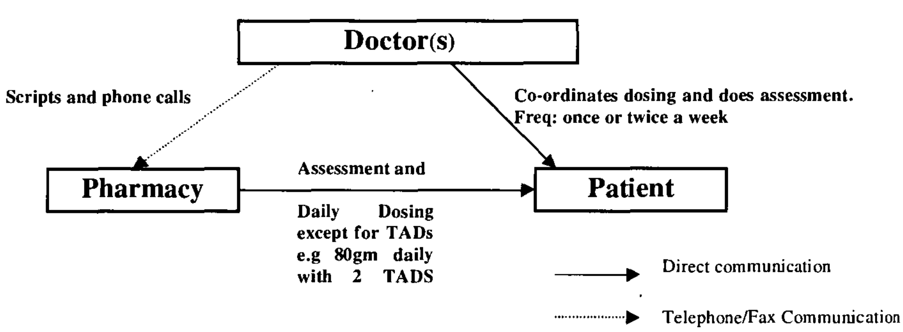


Figure 1-1 Current medical practise in caring for patients with opioid dependence in Tasmania, Australia

However, TADs prescribed in the treatment as an opioid substitute often have a negative social effect due to their diversion (from people in receipt of prescriptions to people not in treatment[8]) and misuse, including overdose and consumption in combination with other drugs.

Therefore, to help the above problem, this thesis proposes a remotely monitored use of TADs and implements and evaluates communication and control methods for remotely supervised medication intake. A tele-drug-rehabilitation system is developed to facilitate remote dosing of TADs (for example at a patient's home) as well as audiovisual interaction between the dosing supervisor and the patient. The challenge is to develop a system where the supervisor can interact "normally" with the patient using web-cameras and microphones. The system should enable the supervisor to make a visual assessment of the patient and afterwards remotely deliver the dose from the dispenser and monitor consumption of the dose. The study presented in this thesis is mainly focused on the design, implementation and assessment of the proposed tele-drug-rehabilitation system supported by some controlled trials.

1.2 Aims

The thesis aims to address the following.

1. What "technical options" are available to solve this problem and what is their performance?
2. How to design, develop and implement a trial system?
3. How functional and useable (i.e. suitable) is the proposed system?
4. What recommendations can be made regarding the use and further development of this system?

1.3 Structure of the thesis

The structure of the remainder of the thesis is as follows:

- Chapter 2 presents a review of literature relating to telemedicine, transmission media, protocols available and Virtual Instruments (VIs).
- Chapter 3 describes the overall concept of the system and the design and implementation of the video communication.

- Chapter 4 describes the design and implementation of the audio communication.
- Chapter 5 describes the design and the implementation of microcontroller programming and communication with the computer for the remote operation of the medicine dispenser.
- Chapter 6 presents the evaluation strategy for the project and analysis of the results.
- Chapter 7 summarises the thesis, discusses advantages and limitations and outlines prospects for future work.

2 Review of Literature

This chapter reviews telemedicine as a general category and explores issues related to applying telemedicine in the rehabilitation of the narcotic patient. Since this project is a subject of telemedicine, a brief review has been done on the meaning of telemedicine as found in the literature, technical terms for the type of work being undertake by the project, the branch of telemedicine it belongs to (if there is any), advantages of telemedicine, available technology and features. The remaining of the chapter presents an overview of transmission media, transmission protocol and softwares used in telemedicine project. A review of different published research papers was done and the review has been presented in a table format. Finally, a literature review on rehabilitation of narcotic patient is presented.

2.1 Terminologies and Branches: Telemedicine, Telehealth and Telecare

This section describes general terms appropriate to describe the type of system this thesis is focussing on. The Oxford dictionary defines telemedicine as the "remote diagnosis and treatment of patients by means of telecommunications technology[1]". Though a layman's definition, it is still useful to get an insight of the basic elements of telemedicine. One of the basic elements is telecommunication. Had not telecommunication developed so much in the last decade, telemedicine would not have come to the stage it is at today. So, telemedicine utilizes telecommunication and information technology for medical diagnosis, treatment and patient care. Telemedicine, which literally means medicine at a distance, incorporates both the delivery of healthcare and exchange of healthcare information over long distances, combining medical knowledge with communications and information technology. It may either be clinical medicine (diagnosis, treatment and medical record) or academic medicine (research, education and training)[2]. In summary telemedicine is *remote medical consultation*. Telemedicine or telehealth has application in just about every branch of medical practice.

Telehealth and telemedicine are often used interchangeably; however, telehealth is a more inclusive and a broader term. Telehealth is the use of information and communication technologies to transfer healthcare information for the delivery of clinical, administrative and educational services. So telehealth care includes telemedicine as well as other services related to health. Table 2-1 below summarizes the salient features of both[2].

Table 2-1 Telemedicine vs. Telehealth[2]

Telemedicine	Telehealth
• Teleradiology • Telepathology • Teledermatology • Telepsychiatry • Focus on discipline/ technology	• Patient Records • Disease Management Information Access • Remote monitoring • Patient compliance • Billing access • Focus on Patient

Telecare, unlike telemedicine, is often used to describe the application of telemedicine to deliver medical services to patients in their own homes or supervised institutions. So given the three different names, *telecare is the best term to describe the current work* since the health. services are provided to the patients' normal location (e.g. their home). There are a number of specific groups of patients for whom telecare is important such as patients with mobility problems, aged patients or those with mental illness. Telemedicine and telehealth may include telecare. However, "Telecare utilizes information and communication technologies to transfer medical information for the diagnosis and therapy of patients in their place of domicile"[3, 4].

Currently, health providers utilize telemedicine in a number of medical fields which is still growing and includes [5-7]

- Radiology (Tele-radiology)
- Pathology (Tele-pathology)
- Psychiatry (Tele-psychiatry)
- Primary Health Care
- Dermatology (Tele-dermatology)

- Dentistry (Tele-dentistry)
- Oncology
- Surgery (Tele-surgery)
- Cardiology
- Pharmacy (Tele-pharmacy).

The author proposes the term ***tele-dosing*** to describe *the use of a telehealth system for remotely monitored intake of narcotic medication.* This term is useful in this case to describe dosing of medicine for narcotic rehabilitation patients, where advantages include control of medicine diversion and misuse and verification of compliance. However, there are other studies done for monitored medication[6]. One of the studies focuses on delivering health care to aged peoples with examples of use in treatment of tuberculosis[8]. The supervision of medication was done through videophone. Improvement on medication using televideo for patients suffering from mild dementia was demonstrated by.Smith, Lunde et al, 2007[9].

2.2 Advantages of telemedicine

Telemedicine has huge potential to impact the way medicine is practised. Telemedicine is more significant in remote and inaccessible areas where it can offer a primary healthcare service. It can provide specialist consultations in areas with low skilled medical personal. It can significantly decrease the time lapse in seeing a doctor or obtaining medical advice from a medical facility especially in case of emergency. Radiology is one field where telemedicine is extensively used[10], followed by home patient monitoring, rural health care and tele-surgery.

To illustrate advantages of telemedicine by a case study, the results of the test of a Virtual Critical Care Unit (ViCCU) has been shown[11]. It used an ultra broadband connection allowing real-time audiovisual communication between clinicians in the emergency department in a hospital at distant sites for the care of acutely ill patients. The results showed that for critical care patients, admissions fell significantly (54% to 30%), transfers increased (21% to 39%), and more procedures were performed. For moderate trauma patients, discharges increased significantly (45% to 63%), transfers decreased (48% to 25%) and treatment times were longer. Even though the test was limited to the Blue Mountains District ANZAC Memorial Hospital (BMH), it definitely provides strong evidence of the improvement of health care with introduction of technology. Telemedicine is one area in Biomedical Engineering that can reduce a patient's costs while improving the patient's experience.

Every case and project is unique. Still there are common general advantages of telemedicine. The most notable advantages [12]:

a. Improved Access: The latest advances in telecommunications, medical devices and electronics can be used to improve health care service availability in remote places or in environments difficult to work for example war zones. There are two approaches to improving health services, either by making services readily available for the first time (e.g. rural), or by improving access to specialty services without the need for the patient to travel a considerable distance to a facility where those services have been traditionally provided.

b. Improved quality of care: Telemedicine provides enhanced decision making capability through technological means. These take place when participants such as the referring physician, the consulting physician, the patient and the patient's family meet together through interactive video. With telemedicine, patient visits to referring and consulting physicians can occur simultaneously, providing the synergy derived from a healthcare "team" approach.

c. Reduced isolation: By connecting doctors to patients in two different places, telemedicine can reduce isolation by providing peer and specialist contact for patient consultations and continuing education.

d. Reduced costs: In many markets, a health care delivery infrastructure exists, but telemedicine is being used to deliver health care services of comparable or higher quality at a lower cost[13]. Current expansion in telemedicine may be attributed in part to the movement to contain costs in healthcare. One of the most obvious cost reductions results from the decreased necessity for travel, including travel expenditure for consultants travelling to remote sites and patients to distant consultants and/or transfers to other facilities. In another example, prisons have used telemedicine to lower the cost of health care delivery, principally through elimination of security, transportation costs and unnecessary emergency department utilization[14].

2.3 Common issues in telemedicine and implications

Issues relating to telemedicine found in literature [15-21] are discussed below.

a. Security and privacy : Security is a key problem of telemedicine especially when data travels over the Internet[17]. There is both network security and end-point security in a distributed environment. Network security concerns relate to a third party between a client and a server. To solve network security public key algorithms consisting of a Secure Sockets Layer(SSL) on top of TCP/IP layers could be used[17, 18]. SSL encrypts the data. The software should be programmed to address the end point security. When it comes to narcotic rehabilitation programs, privacy and confidentiality are very important. However, compared to paper systems electronic data bases can provide higher protection of information.

b. Reliability and availability: The technology used should be reliable and easily available. If technology chosen is unreliable, it may not be perceived well by patients and lead to discontinuity of trials. Undetected errors in development of system may accumulate. So the consequences of the error in the system should be taken into account[15].

c. Maintainability: Maintainability relates to the ease with which changes can be made to programs in case of bugs or changes in user requirements. Especially in systems dispersed geographically, it is important to consider how upgraded or repaired software may be disseminated to the users simultaneously[16].

d. Capacity and scalability: Once a system is implemented addition development may be required. So any telemedicine system should be scalable so that it can cope with additional developments and requirements that were unseen before and comes as the system develops and with results. Capacity means dealing with the amount of data generated[16].

e. Adequate bandwidth: The bandwidth should be adequate to transfer audio, video and other data. With the rapid development of internet technologies, it is possible to transfer large amount of data[15]. However, most rural areas who can benefit most from telemedicine systems still do not have high bandwidth telecommunications access required[22] .

f. Risks and Standards: Since telemedicine is directly involved with humans and their medical care, there are potential risks to their safety. So the government regulations usually don't allow a telemedicine system to be used in public health unless it is proved to be safe. Developing standards would minimize the cost of newer developments[19].

g. User friendly: Telemedicine systems should be easy to use. Even if the technology used is very sophisticated, the operation should be effortless for the user. Portability of the system is a useful feature for ease of use[16].

h. Interoperability: Telemedicine hardware and software developed by one developer should be able to interact with other systems to reduce development cost and increase flexibility[21].

i. Non-Technical: There is lack of proper legislation regarding health care through the internet. Important issues like physicians providing inter-state services but only being registered in their state have to be addressed. There is also a problem of telemedicine not being covered by normal health insurance[20].

j. Adequate training: Since telemedicine uses technology including computers, training for the clinician and the patient to use the telemedicine system is important. Insufficient training can hinder the clinician as well as the patient to fully utilize a telemedicine system and efficiently[23].

k. Change management: A structured approach is required for transition of the patients and the clinician involved in a telemedicine project to use the technology involved and the new changes that it brings. Telemedicine should be designed in labs considering the settings of real world. A telemedicine project should be well planned to completion with aim of the end result and not just for best performance in the testing phases[24].

2.4 Challenges in designing telemedicine system

Technology to be used in particular telemedicine systems should be carefully chosen. Six challenges in designing a telemedicine system as mentioned in [25] are:

a. A design that is not obsolete at the end of depreciation cycle.

b. Creating an architecture that allows the hospital to decide which portion of the system it needs while allowing expansion to the full system, if necessary.

c. Incorporating new technologies into the design.

d. Integrating the system with the informatics infrastructure of the hospital.

e. Smooth interoperation with the local area network.

f. Compatibility with the various telecommunications services of the health care network of the hospital.

The challenges are relevant even in the present context. More importantly it explains the need for telemedicine system to be adaptive.

2.5 Synchronous and Asynchronous Telemedicine

Telemedicine can be either synchronous or asynchronous. Synchronous telemedicine is a real time telemedicine system and in asynchronous there is no direct connection between the concerned party and information is stored and retrieved at suitable time. This section gives a brief description of the two types.

Basically, all telemedicine projects can be broadly divided into two categories. They are

a. Synchronous or Real time telemedicine applications,

b. Asynchronous or Store-and-Forward telemedicine applications.

2.5.1 Synchronous or Real time telemedicine

The concept of operational deadlines from event to system response gives rise to a "real time telemedicine system". Teleconferencing is one example of this system. Most of the telemedicine systems are real time. There are a number of examples of tele-consultation in psychiatry[5] which is one form of real time telemedicine. Real time interactive telemedicine normally consists of video conferencing though it can be as simple as a phone call or transmission of vital signals [26-28] or using a webcam and ADSL[5]. However, high bandwidth video conferencing is the main feature of telehealth or telecare. It is used in medical personnel education, peer consultation and patient education as well as direct patient care, rehabilitation or aged care[29, 30]. The last decade has seen an exponential increase in use of telemedicine video conferencing because of development of technology and increase in band width. Decreasing cost of computers has also helped in development of real-time telemedicine. Areas of use have expanded to include remote surgery. The internet is a widely chosen medium as an economical method to communicate between expert medical services to patients in remote locations.

There are a number of ways of performing video conferencing. Peer-to-Peer (P2P) is a type of Internet network allowing a group of computer users to connect with each other for the purposes of directly exchanging data[26]. Both clients and servers are Peers. Each computer in this architecture can act as either a client or a host server which enables the computers to share resources directly with each other so in effect the communication is decentralized. The P2P greatly reduces the network traffic and allows each computer to utilise the system's processing power and storage capability. Every peer has the same status and could set up a communication without the server. Most instant messenger software like Microsoft's MSN messenger is based on the P2P network.

Client Server software architecture is an alternative way of performing video conferencing. It distinguishes client systems from server systems. In this architecture a client always initiates a dialogue request for services and the server provides it[31]. Client server architecture lacks the robustness of a P2P network because of traffic congestion when simultaneously a number of clients simultaneously make request to the same server or when the server is down.

However, not every telemedicine incorporates a teleconferencing system which is more expensive than the other model 'Store-and-Forward' because you have to maintain a continued connection with the World Wide Web in this.

2.5.2 Asynchronous or Store-and-Forward telemedicine

Store-and-Forward is a telecommunications technique in which information is sent to an intermediate station where it is kept and sent at a later time to the final destination or to another intermediate station. It is also called asynchronous communication.

The store-and-forward model is more practical than real-time telemedicine because it eliminates the need for scheduling[32]. It also decreases the bandwidth requirement. Email can be used as a mean of communication instead of the widely followed architecture of videoconferencing. Advantages of store-and-forward telemedicine strategies include simplicity, low cost, and minimal infrastructure requirements[33, 34]. It is more convenient than scheduled synchronous or real-time tele-consultation. It is less disruptive to physician and patient schedules, and requires far less technical and bandwidth support. Because of the asynchronous transmission of data the delays of the network are less important and thus a lower bandwidth network can be used for transmission of large data. Furthermore, the consultation procedure is also quite easy because of the fact that both sides can interact with the system independently[34]. Dermatology[35], radiology and pathology are common specialties that are conducive to asynchronous telemedicine. It is also commonly used for specialist review cases when convenient. However, this type of system can not be used in emergency situations[36].

As an example of how a store-and-forward system can be implemented, a system with a three-tier application using Internet Information Server (IIS) and Microsoft SQL Server 7.0 running on Windows 2000 Advanced Server and Windows 98 with Internet Explorer 5.5 on the client side has been implemented in [32]. VB Script is used to generate text of the web pages. A Java application runs on the server for emailing. One of the notable points is that it uses Microsoft DirectShow API to control a video camera.

2.6 Transmission media

This section reviews transmission media chosen in different telemedicine applications. Depending on the specific application, telecommunication media required would vary in complexity. However, the technology required for most of the telemedicine projects is available even if at various degree of efficiency and various level of cost[21]. Normally real-time telemedicine applications require high bandwidth. The internet which can also be called network of networks is a natural choice for most telemedicine projects[37]. It is a packet-switched network.

The different types of media currently available are:

1. Local Area Network (LAN) (wired or wireless): LAN is a collection of two or more computers. It is characterized by limited distance to each other and connected directly or indirectly. LANs may have different topology depending on the way the computers are connected, in how information moves around the network, and in what machine (if any) is in charge of the network. LAN has several physical topologies, including bus, ring, star, tree, and star-wired ring. It has different speeds depending on the topology. Ethernet, the most frequently deployed networking technology, supports speeds of 10 Mbps[38] to 100 Mbps[39]. LAN is often used as a test bed for telemedicine applications. Wireless

LAN is a preferred topology in hospitals[39] because of ease of movement and speed.

2. Wide-Area Network (WAN): Unlike LAN, WAN has computers separated by longer distances. WAN interconnects computers that are geographically dispersed. Because of the distance, the bandwidth is slower and is measured in kbps compared to megabits per second (Mbps) for LANs. WAN has a different medium for transmission. One can use leased lines, fractional T1, T1 or T3 lines for permanent connection. PSTN or a number of switched digital methods is also alternative transmission medium[38]. WAN is a popular medium used in telemedicine.

3. Integrated Services Digital Network (ISDN): ISDN is a telecommunications standard that is used for sending digitally encoded voice, data, video, and other signals on the same lines. ISDN also provides access to a variety of communications, information processing, and supplementary services. ISDN is a completely digital service. An ISDN implementation must provide any adapters needed to translate analog or non-ISDN compatible signals. ISDN supports bandwidths of about 2 Mbps. It uses a single digital link to get the gamut of a user's communications devices (telephone, fax, computer, or video) onto the ISDN lines. [40]uses ISDN as a communication medium for ECG.

4. Wireless Internet: The wireless internet technologies are Global System for Mobile Communications (GSM), General packet radio service (GPRS), Enhanced Data Rates for Global Evolution (EDGE), Code Division Multiple Access (CDMA), 3G and 3.5G. Wired Internet limits communications between fixed locations which may be an inconvenience. Development of mobile communication technologies, such as GSM, GPRS and especially 3G networks has increased the geographical area covered by medical services. More and more new applications in health provision use 3G technologies to provide a broadband, packet based transmission of text, digitized voice, video and multimedia at data rates up to 2 Mbps. GSM is considered the 2G (second generation) of wireless technology. GPRS, EDGE and CDMA are considered as the 2.5G generation. The different wireless internet technologies are discussed in next point under individual headings.

5. Global System for Mobile Communications or Global Special Mobile (GSM): GSM is the digital cellular standard in the 900 MHZ band. Its services include telephony, asynchronous and synchronous data services (2.4/4.8/9.6 Kbps) and value added features (SMS, fax)[41]. Speech is digitally encoded and transmitted as a digital stream. GSM users can send and receive data, at rates up to 9,600 bps. Public use started in 1991. The method chosen by GSM to divide up the bandwidth among as many users as possible is a combination of Time- and Frequency-Division Multiple Access (TDMA/FDMA). The FDMA part involves the division by frequency of the (maximum) 25 MHz bandwidth into 124 carrier frequencies spaced 200 kHz apart. One or more carrier frequencies are assigned to each base station. Each of these carrier frequencies is then divided in time, using a TDMA scheme. The fundamental unit of time in this TDMA scheme is called a burst period and lasts 15/26 ms (or approx. 0.577 ms). Eight burst periods are grouped into a TDMA frame (120/26 ms, or approx. 4.615 ms). GSM was the first communication medium used for mobile telemedicine[42]. It was used to send Electro Cardiogram (ECG) and Photoplethesmography (PPG) data. It is the second generation of mobile communication[43].
6. General Packet Radio Service (GPRS): GPRS is the packet-mode extension to GSM[41]. GPRS was first trialled in 1999, 8 years after GSM. GPRS is a non-voice, value added, high-speed, and packet-switching technology for GSM networks. It can send and receive small burst as well as large volumes of data. It is packet based, it increases data transmission speeds, and the user no longer needs to dial up to a separate ISP. GPRS users are considered to be always connected. Packet switching means that GPRS radio resources are used only when users are actually sending or receiving data. Theoretically, a GPRS connection can provide a data transmission speed of up to 171.2 Kbps (approximately three times as fast as the data transmission speeds of fixed telecommunications networks and ten times as fast as the GSM network services) if all eight slots are used. However, it is unlikely that network operators will allow a single user to use up all the time slots. Normal rate is 56 Kbps. The fewer the timeslots provided per user, the lower the data transmission speed. It is the 2.5 generation of mobile communication[43].
7. Enhanced Data Rates for Global Evolution (EDGE): EDGE increased the GSM/GPRS data rates by up to three times[44]. EDGE uses the TDMA frame

structure like GPRS and the same logic channel and 200- KHz channel bandwidth as the GSM networks. It can provide data throughput over 400 Kbps per carrier with 473 Kbps per user at peak. Adaptive modulation and coding scheme is applied to enhance the speed.

8. Code Division Multiple Access (CDMA) 2000: CDMA2000 belongs to 2.5G Generation. It uses the spread spectrum communication technology. It has much higher bandwidth than information channel. Introduction of CDMA has been a major step in development of mobile telemedicine. CDMA2000 has been used for multi-user real-time monitoring of ECG signal[28].

9. Third Generation (3G): For 3G standards there are several technologies available globally. Based on their basic technology, they are WCDMA, advanced TDMA, hybrid CDMA/TDMA, and orthogonal frequency division multiplexing (OFDM). WCDMA was developed in Japan. The 3rd Generation Partnership Project (3GPP) is the joint agreement between major technologies in the world with aim of producing globally applicable technical specifications for 3G[43]. Universal Mobile Telecommunications System (UMTS) is the 3G introduced in Europe. UMTS is one of the implementation of the 3G Telecommunications Systems[41].. It is a significant improvement over 2G and 2.5G systems because of their high operating flexibility, their ability to provide a wide range of applications and generally extend the services now provided to fixed networks users to mobile customers. When conceived, UMTS aspired to provide bit rates up to 2 Mbps to low mobility users and up to 144 Kbps to high mobility users, while being compatible with the 2G GSM system.

10. High Speed Downlink Packet Access (HSDPA): HSDPA is a major work item for Release 5 in 3rd Generation Partnership Project (3GPP). 3GPP specify the standards used by Mobile Network. It was developed by global collaborations of telecommunications associations. HSDPA is a combination of several techniques that all contribute to the enhanced capabilities of the downlink channel. HSDPA is currently provided by Telstra with an advertisement download speed of 1.7 Mbps.

2.7 Transmission Protocols

This section explains different transfer protocols that are available for data transfer across the internet. The transport protocol encapsulates data blocks into data units making it suitable for transfer to the network infrastructure for transmission to the destination host. It also does the reverse function of abstracting the above data units and delivering the encapsulated data to the end user-application. Since these protocols act as virtual host-to-host communication transport medium for applications, they are referred to as transport protocols. A transport protocol forms data packets of data to be transmitted over the internet and adds source and destination IP addresses and port numbers in the header of each transport layer data packet. Three types of protocols are popular to transfer digital data over internet – TCP (Transfer Control Protocol), UDP (User Diagram Protocol) and RTP (Real-time Transfer Protocol). The protocol used determines addressing, reliability of data transfer, segment order maintenance (the order in which data segments reach the application compared to the order they left the sender), flow control (the data sending speed should adapt itself to the receivers speed) and congestion (the transmission speed cannot be faster than the speed of the slowest link traversed on the connections path). Though used in the internet, it can also be used as a communications protocol in a private network. The three protocols have further been described in the following paragraphs:

a. TCP: TCP is a connection-oriented protocol. It is reliable and retransmits lost data[45]. TCP has a higher overhead compared than UDP. It has congestion control mechanism. It saves a copy of data transmitted which is deleted from queue when acknowledgment is received for the data. If no acknowledgment is received before the timer runs out, the segment is retransmitted.

b. UDP: UDP is a simpler protocol. As defined in RFC- 768[46], UDP only adds transport-level addressing and an optional checksum to the Internet Protocol (IP) service of best effort datagram delivery. UDP has a source port number destination port number, UDP length and UDP checksum and data. So the header is of fixed size of 4 bytes compared to 20 bytes in TCP. UDP is effective for time sensitive applications where the reliability of delivery is not as important as timely delivery such as the case of Audio. It does not have congestion control mechanism.

c. RTP: RTP is a protocol mainly used for delivering audio and video over the internet[47]. It provides end-to-end delivery services for data with real time characteristics such as interactive audio and video. It also supports data transfer to multiple destinations using multicast distribution[48]. It doesn't guarantee any quality of service. However, Real Time Control Protocol (RTCP) is used to support this protocol by providing feedback. RTP basically sends audio data in small chunks, for example 20 ms. Each segment of audio data is preceded by an RTP header. The RTP header and data are in turn contained in a UDP packet.

2.8 Standards in video conferencing for telemedicine

This section describes the standards used in video conferencing. Standards, the universally agreed upon set of guidelines for interoperability, are the key to any research work so that not everything has to be done over again. The project follows one of the common standards for video conferencing.

Video Conferencing requires a significant bandwidth. So generally video are compressed before transmitting. Compression reduces or eliminates redundancy in data representation and hence saves storage and communication costs[49]. ITU defines a number of standards for video and audio streaming. Video compression can be done in three different ways which can be categorized into (1) entropy (lossless coding), (2) source (lossy coding) and (3) hybrid coding[50]. Entropy coding, a lossless coding, (e.g. Huffman coding, run length coding) is a reversible process with the perfect recovery of original data. The quality of recovered data is same as the original. In this coding the data are processed just as a sequence of digital values. Source or lossy coding is an irreversible process where the data is degraded; however, it need not necessarily affect the perceived quality. It considers the semantics of the data to be encoded, separating relevant and irrelevant data. Hybrid (e.g. JPEG, H.261 and MPEG) coding combines both lossy and lossless coding. H.261, H.263, MPEG-1, MPEG-2, MPEG-4 [26] and MJPEG are the most popular video codec standards.

JPEG stands for Joint Pictures Experts Group. Joint because the development of this standard was a joint effort of CCITT and ISO. JPEG is a compression standard for continuous tone still images (greyscale and colour). JPEG is supposed to be a generic standard for many image applications. It offers one lossless and three lossy encoding modes: sequential, progressive, hierarchical. There is really no such standard as "motion JPEG" or "MJPEG" for video. MJPEG is basically individual frames of video sequence. JPEG is designed for compressing either full-colour or grey-scale images of natural, real-world scenes[51]. It works well on photographs, naturalistic artwork, and similar material; not so well on lettering, simple cartoons, or line drawings. JPEG can typically achieve 10:1 to 20:1 compression without visible loss, 30:1 to 50:1 compression is possible with small to moderate defects, while for very-low-quality purposes such as previews or archive indexes, 100:1 compression is quite feasible. Non-linear video editors are typically used in broadcast TV, commercial post production, and high-end corporate media departments. Low bit rate MPEG-1 quality is unacceptable to these customers, and it is difficult to edit video sequences that use inter-frame compression. Consequently, non-linear editors (e.g., AVID, Matrox, FAST, etc.) will continue to use motion JPEG with low compression factors (e.g., 6:1 to 10:1)[52].

Audio is an important section of video conferencing in telemedicine. The slight time delay in receiving the audio makes natural conversation difficult and impedes the ability to exchange ideas[53]. The human frequency band ranges from 100 Hz to 9 KHz, however normally human frequency is below 2 KHz and 4 KHz is accurate enough to replicate human voice[26]. A number of compression algorithms are available like MP3. Wav format is an uncompressed audio format.

There are standards developed for web interface and point of access for patient interaction to telemedicine services as well[54]. There are standards for web security like SSL Protocol[54]. SSL Protocol uses a combination of symmetric and asymmetric cryptography to secure a communication between a web server and a web browser. There are standards developed for imaging in telemedicine like DICOM (Digital Imaging and Communications in Medicine)[55]. DICOM is a specification for interoperability of medical imaging the Digital Imaging. It defines the information storage format and protocols needed for handling of digital clinical images. DICOM specifies the method and formats used in the exchange of images between medical imaging devices. It also deals with standards for few other types of data, for example waveforms and the related information to reference other images. For plug and play operation of devices, IEEE 1073 has specified standards. It is also known as the Medical Information Bus (MIB). Examples of devices where the specifications can be used are vital signs monitors, infusion pumps and defibrillators[56].

2.9 Common features of various telemedicine projects

A study on current use of different technologies in various telemedicine projects used for literature review as done. The summary of seventeen papers has been presented in the Table 2-2. The motivation was to get some idea on different features of a telemedicine project. Ten different categories were made and points taken from each of them. The area looked at were - cost, type of communication video, audio or data, acquisition device, compression of data, system used, bandwidth required, resolution of images, software used, architecture followed and area of use. Any special features were listed under remarks.

In the literature studied, it was found that cost was not a major outcome of telemedicine research unless it was specifically designed to be a low-cost system. Video communications, text based messages and signals (for example ECG data) were used. For video communication, USB cameras were found to be used most often [47, 51], however a microscopic CCD camera was used for specific purpose[25]. For compression of video, JPEG 2000, MJPEG, MPEG4 and H.263 were used in the papers reviewed. Java, Visual C and LabVIEW were used in most of the projects[51]. Bandwidth required varied from 9.6 Kbps to 2 Mbps. The telemedicine projects were both real time and store-and-Forward type. The different areas of research were aged care monitoring, emergency services, intra-hospital patient transport, disaster monitoring and medication management and scheduling.

1. A novel image Capture System for use in Telehealth Applications[57].
2. A clinical monitoring and management system for residential aged care facilities[58].
3. A Mobile Teleconference System for Homecare Services[47].
4. A CORBA based Telemedicine System for medical image analysis and modelling [59]
5. @HOME: A modular telemedicine system [60]
6. A multiagent telemedicine system[61].
7. A multimedia telemedicine system[62].
8. A Novel Mobile ECG Telemonitoring System[28].
9. A Simple System for Telemonitoring the Daily Life of An Aged Person Living Alone[63].
10. A Web-based Mobile Medical Monitoring System[64].

11. Web-based Home Telemedicine System for Orthopaedics[32].
12. Implementation of a WAP-Based Telemedicine system for Patient Monitoring[65].
13. Multimedia Features of a Dynamically Adaptive Telemedicine System[25].
14. A wireless PDA-Based Physiological Monitoring System for Patient Transport[66].
15. Multipurpose health care telemedicine systems with mobile communication link support[67].
16. Remote monitoring of vital physiological signs[68].
17. WISTA: A Wireless Telemedicine System for Disaster Patient Care [51]

Table 2-2 Features of different telemedicine system

Serial No / Ref No	1 [57]	2 [58]	3 [47]	4 [59]	5 [60]	6 [61]	7 [62]
Cost	Low Cost		Low cost				
Video/Audio/Data	Video	ECG, weight scale	both	Images	Sensors		Both
Acquisition Device	Consumer digital camera		USB Camera		4 sensors-oxy saturation, B.P, ECG, Medication Dispenser		SAA7113H Digital Video Decoder / TDA1309 Audio ADC / DAC
Compression	JPEG2000		70% compression ratio				MPEG4, MP3; Real time
System	Picture transfer protocol(PTP)		RTP for voice		GSM and TCP/IP		
Bandwidth (UP /Down Kbps)			64 / 384				
Resolution of image			640 x 480				6144* 6144 pixels, 12-bits depth of color
Software			Java	CORBA/ Java		JAFMAS* Java	Visual C++ 6.0
Architecture		Client-Server	teleconference		CCS[1],Health record system / Database, CUI[2]		real-time video, audio and instant message, and non-real time data (medical image)
Area Used for		Age Care	home care	Medical image analysis			
Remarks	JPIP* standard (HTTP) for progressive Transmission	Scheduling and medication management	mobile	Remote Method Invocation		seven agents	dynamic IP address (cost reasons)

Ref no.	8 [28]	9 [63]	10 [64]	11 [32]	12 [65]	13 [25]
Cost						
Video/Audio/Data				Video/Text	Text Based Message	Audio/Video Informatics
Acquisition Device			Transducer		Transducer(Ag-AgCl pre-jelled electrodes)	Microscopic CCD camera
Compression				H.263 codec QuickTime		8 bit μ law for audio/ NTSC, VHS,PAL-video
System	CDMA1x, GPSOne		FM/Transceiver /Webbased	E-mail	WAP 1.1 at GSM 1800MHz	Modem/ Switched 56 and ISDN/ fractional T1 / Inverse multiplexed T1s
Transmission Rate(UP /Down kbps)	170 kbps			128 kpbs	171. 2kB/s (1370kbps)	28.8 / 56 / 128 / 336 to 1544 Kbps / 2 Mbps /44.736 Mbps
Resolution of image						Adaptive (max 2K x 2K)
Software		'OpenSSH protocol 2','cron',		Java(email), IIS, Microsoft SQL server	WML/WMLScript,Perl,MySql	
Architecture		power consumption of home appliances		Store-and-Forward		DAMDW*
Area Used for				Orthopaedics	BP / ECG	Radiology, ultrasound, pathology studies(cytology), endoscopy
Remarks		Electrical appliances for monitoring		Security SSL(Secure Socket Layers)		Adapts to the physician and to the bandwidth available

Ref no.	14 [66]	15 [67]	16 [68]	17 [51]
Cost				Cost-effective
Video/Audio/Data	Vital signals	ECG, SpO2, NIBP, IP, Temp, Resp	ECG and SpO_2	video, medical image, text and ECG
Acquisition Device	Pocket PC/ PIC16F877	Biosignal acquisition module and digital still camera	Data acquisition card	IEEE 1394 webcam and a USB webcam
Compression		Huffman coding algorithm		15:1 to 25:1for MJPEG, JPEG for still images
System	WLAN	GSM, satellite and POTS link	Local Computer	UDP for video, TCP for data, 802.11g network
Transmission Rate(UP /Down kbps)		9.6kbps-GSM, 56Kbps POTS		20 Mbps
Resolution of image	11 Mbps			320×240 for video,
Software	Borland C++	Paradox 7 and Borland Delphi 4	LabVIEW and .Net	LabVIEW
Architecture	Mobile Unit.Consultation terminal, Management uni	A telemedicine unit (portable or fixed) and a base unit (doctor's unit) located at hospital	Data stored in local computer	Control centre, local server and end device (PDA and RFID)
Area Used for	Physiological data	Emergency health, Intensive care patients monitoring, Home telecare	monitoring ECG	On-site patient care for disaster patient
Remarks	For intra-hospital patient transport	Critical care telemetry	To reduce travel time for specialist.	Simulations used to get the results

2.10 Software used in telemedicine

Selection of appropriate software is a key consideration for any telemedicine project. Common softwares used in telemedicine are Java, .Net, Visual C, Visual Basic and LabVIEW. Visual Basic is a straightforward and powerful programming language for telemedicine because of its ability of visual programming tools[69]. For low system development costs, free softwares and open source programming languages such as Java, HTML, XML, SQL together with Linux are used[70]. Another powerful programming language Java was designed for various applications types and is popular in telemedicine applications[71, 72]. One major advantage of Java is it can run effortlessly across heterogeneous platforms[72]. LabVIEW works on Virtual Instruments (VIs). VIs can be defined as software based instruments that are programmed to look like the physical instrument panels, including switches, sliders and indicators[73]. VI is a popular and proven method in the field of biomedicine to acquire data and for controlling systems[74]. The reliability of information, an interactive and effortless interface and ease to integrate with installed equipment are the features of VIs. Alternatives such as Java applets may be cheap, platform independent and equipped with a rich library for telemedicine applications. However, since VIs provide advanced signal processing capability, ease of programming because of the graphical nature of LabVIEW and cost effectiveness, VIs are often preferred[75]. For example, VIs developed in LabVIEW have been used for vital sign tele-monitoring and recording for telemedicine applications[76]. LabVIEW is compatible with all network protocols like TCP and UDP, GBIP and USB DAQ cards and LAN or WAN networks[77]. VIs are one of the preferred coding styles [75] for telemedicine projects. They also enable integration of sensors by a computer equipped with specific data acquisition hardware and software to permit measurement data acquisition, processing and display[78]. VIs are a new generation of instruments that leverage the computational power, digital I/O, memory and storage, and sophisticated graphical programming capabilities of the modern computers[79]. Virtual Instrumentation places emphasis more on the software and computer than on electronics and ICs. Reduced development time is one of the strongest points of using VIs.

2.11 Rehabilitation of narcotic patients

The section is a summary of treatment of narcotic patients and the problems faced in the treatment. The opioid maintenance program to treat opioid drug dependence is a supervised drug administration program. It is also called "direct observation of treatment". There are two substitutes mainly used, Methadone and Buprenorphine. Opiates are central nervous system depressant drugs that cause drowsiness, a sense of a high and ultimately they can cause unconsciousness, coma and death from respiratory centre depression. "Supervision of dosing permits assessment of the patient before dosing and to minimise harm from drug overdose, abuse and diversion"[80]. In the early 1970s, there were concerns over diversion of Methadone. Overdose fatalities resulting from use of diverted Methadone led to regulations for strict direct observation of doses taken. Diversion may either be defined broadly as both inappropriate use of medication by those for whom it has been prescribed, and use by people for whom the medication has not been prescribed. However, with the introduction of Buprenorphine, TADs were gradually allowed. TADs not only promote rehabilitation and improving retention in treatment, they also help to reduce congregation at dispensing points and improves access to treatment by reducing travel difficulties[81].

Compared to Methadone, Buprenorphine has lower risk of fatal overdose and the time between two doses is significantly longer so requiring fewer TADs[82]. A number of patients are able to stabilise on one dose every two days, potentially halving the amount of contact that they would need to have with the pharmacy when compared with a Methadone program, and resulting in less expense. Additionally the side-effects associated with Subutex© are considered to be far less intense than those experienced from Methadone.

However, the risks of injecting diverted Buprenorphine as well as diversion of Methadone and consumption by an opioid naive person are potentially lethal. In research done on Methadone injecting patients, 30% of those either always, usually or sometimes sold part of their Methadone to others [83] out of 134 respondents in a study undertaken by National Centre in HIV Social Research, The University of New South Wales. According to the Australian Bureau of Statistics report Drug Induced Deaths, Australia, 1991-2001, the number of deaths in 2001 caused by Methadone was 32, out of that 25 being accidental (overdose) and 7 being suicidal[84]. Buprenorphine has been the most frequently used drug of abuse. It is usually crushed and injected. Availability of diverted Buprenorphine has been said to be the reason for 80% increase in the number of injecting opioid dependent people in Tbilisi, capital of Georgia, between 2003-2006 raising total number of drug users beyond 250,000 in a population of just 5 million people[85]. So there are a number of risks associated with TADS including injecting, overdose from diverted TADs. Diverted TADs being sold on the black market and deaths of children associated with TADs. This has contributed to a poor public opinion of drug treatment programs.

[86]compared the relationship between Methadone take-away policy and rates of Methadone injection in six different states in Australia. The paper points out a number of influencing factors such as take-away policies, drug preference, drug availability, treatment availability and degree of treatment penetration. One of the conclusions of the author is where there is no heroin available there is a greater pressure to divert unsupervised doses.

Often issues related to misuse of opioid substitute have been raised to ban their use, however very few works can be found in the literature to control illicit traffic in Methadone obtained legally, to control the Methadone dosages administered and cheaters who visit several clinics. There is also a lack of published works on technologies to remotely monitor the consumption of unsupervised doses. Though techniques to use technology to automate the Methadone TADs dosing system has been proposed as early as 1972[87], there are none that have been documented as being used in practise.

3 Methodology

3.1 Remote Monitoring and Control System

The Remote Monitoring and Control System (RMCS) for tele-drug-rehabilitation facilitates the opioid dependent patient undergoing drug rehabilitation. The system has been designed to allow patients to be dosed at their convenience without disrupting normal daily life activities such as work, family commitments and travel while reducing the risk of Buprenorphine (used in the program) being abused. The RMCS has a dedicated server and a client or patient side computer for each patient. An electromechanical dispenser is attached to each client computer[89]. The client is connected via cable or wireless broadband internet. The system is portable, real time and replaces face-to-face assessment and supervision of dosing. Teledosing is an integral part of RMCS. The next section details the complete RMCS system.

3.1.1 RMCS System

The Remote Monitoring and Control System incorporates clinician, pharmacist and patient roles similar to in normal opioid dependence care as well as a narcotic centre and a central server (Figure 3-1). The patient has an electro-mechanical dispenser, computer, webcam and headset. The Dosing supervisor also has a webcam and headset for video and audio communication respectively.

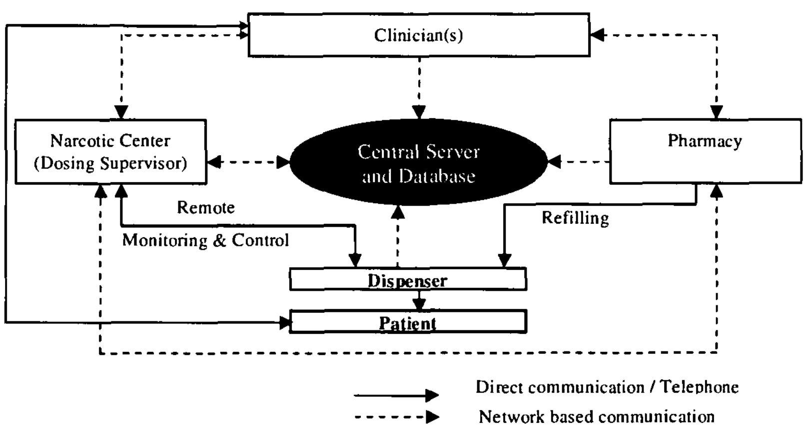


Figure 3-1 Complete picture of Remote Control and Monitoring System

The central server is a common database and is shared by the clinician, dosing supervisor at the narcotic centre, pharmacist as well as the dispenser. The patient communicates directly with the clinician, the narcotic staff and the pharmacy. However the clinician, dosing supervisor and the pharmacist only share information through the central database or communicate through the network.

The dosing supervisor at the narcotic centre monitors the remote dispensing. This is the most active connection. The clinician makes recommendation for patients to be suitable for tele-drug-rehabilitation, assesses patients for their improvement as well as writes scripts for the narcotic replacement medicine. The pharmacy refills the dispenser for a week based on the script from the clinician.

Of the system described above, the remote monitoring and control part is implemented and trialled in the current project. This part has been further explained in next section.

3.2 Implemented Remote Monitoring and Control

Of the above mentioned RMCS design (Figure 3-1), the remote monitoring and control system has been developed and trialled. It involves two parties – the patient participating in tele-drug-rehabilitation and the dosing supervisor performing tele-dosing Figure 3-2.

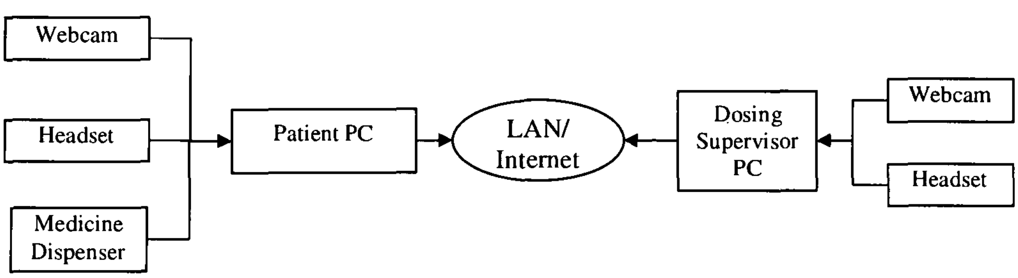


Figure 3-2. The connection and components of the remotely monitored medication dispensing

The patient side or the client side has a computer or laptop with a webcam, a headset and medicine dispenser. The clinician side also has a webcam and a headset. The two are connected through the network (LAN or internet).

The steps for the tele-dosing are shown in Figure 3-3. The goal is to dose medication to the patient. The patient logs in to the program by entering password. The program at the client end connects to the computer with the dosing supervisor. This starts two way interactive audio-video communications.

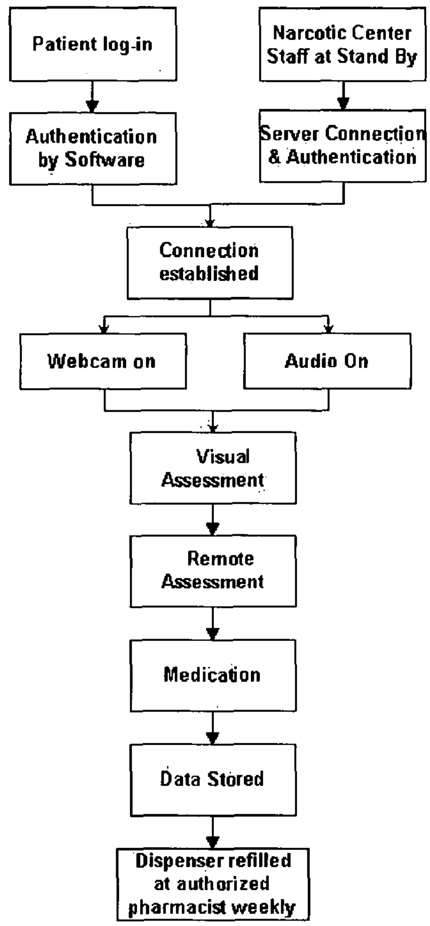


Figure 3-3 Flowchart of steps for remote medication dispensing

The dosing supervisor then visually assesses the condition of the patient. In the future, it is intended to assess the patient for dosing using objective remote assessment techniques such as Pupillometry – this is being developed in our Biomedical Engineering Research Group. If the patient meets the required conditions, s/he is then dispensed with a dose of Burprenorphine through a mechanical dispenser. The idea is to give the patient TADs for 7 days so s/he would have to visit the pharmacy only once a week.

Two Dell laptops with Pentium M 1.5 GHz processor are used at each client and server side. The architecture of the system is based on client-server model. Logitech webcam were used. For audio communication 3.5 mm mini plug headphone and microphone were used.

3.3 Software and Devices

The software used for the video communication system is LabVIEW 8.5.1 together with NI-IMAQ Vision Development 8.5.1, NI-IMAQ Vision Acquisition 8.5.2 and NI-IMAQ for USB 1.2. Executables of the software was made and used in the trials.

Webcams are used for the video communication in the project. The affordability of web cameras makes them an ideal choice. The Logitech QuickCam camera manufactured by Logitech Inc was used for the video. The camera has a CMOS image sensor with a maximum true resolutions of 352x288 (software enhanced 640x480) Table 3-1. It has drivers for both Microsoft Windows and Linux Operating System. Other specifications are:

1. Quality CiF (352x288) CMOS webcam
2. Video capture: 640x480 pixels (software enhanced)
3. Still image capture: 640x480 pixels (software enhanced)
4. Frame Rate: 30 frames per second (in test environment)
5. Manual focus

LabVIEW can grab images in 5 different resolutions (including software enhanced) which are shown in Table 3-1. Software enhancement is increasing the resolution size mathematically.

Table 3-1 Resolution for corresponding mode

Video Mode	Resolution
2	160x120
3	176x144
4	320x240
0	352x288
1	640x480 (Software enhanced)

4 Video Communication System

The video system enables identification of the patient, visual assessment of the patient. by the clinician and monitoring of the dosing. The video communication system needs to provide short, synchronous and highly engaged face-to-face interactions. The clinician and the patient see each other by video communication system. The clinician also uses the system to see the medication being dispensed and dissolved. The system includes two computers with webcams, connected through a network.

The approach followed in this section is to first discuss the transmission format used in the program and then the development of the video communication software in LabVIEW. The evaluation of this system in discussed separately in Chapter 7 Evaluation.

Coder and decoder (codec) are required for video communication so that the video data can be compressed before sending. CODEC are software codes or hardware that can compress and decompress data. The image frames are captured in RGB format which is the raw format. There are a number of video codecs available - H.261, H.263, MJPEG (Motion JPEG), MPEG1, MPEG2 and H.264/MPEG4[89]. MJPEG format is used in the current project for video. MJPEG is a generic term for video capture formats that make use of a stream of individually encoded JPEGs. MJPEG is a lossy compression method. MJPEG generates a sequence of key frames. Since it implements an intra-frame coding technique, loss of one or more frames do not affect the quality of another frame but only affects the frame rate. The simplicity of working with MJPEG has made it the preferred codec for the project. Literature shows that video stream encoded using MJPEG at a frame rate of 20 fps(frames per second) requires bandwidth of around 750 Kbps[90]. Normally a video fidelity of 320X240 pixels at 15 frames per second is adequate for inter-personal communication[91].

There are three communication protocols that can be used – TCP, UDP and RTP. RTP (Real Time Protocol) is the Internet-standard protocol (RFC 1889,1890) for the transport of real time data including audio and video[92]. LabVIEW doesn't have libraries for RTP so it was not considered. TCP (Transmission Control Protocol) is used as the communication protocol for the video communication in the current project. UDP (User Datagram Protocol) could have been used but while TCP is slower as well as consumes more bytes than UDP, TCP has its own congestion control mechanism. Since video consumes a huge chunk of bandwidth, congestion is more important than delay in frames so the delay has been accepted as a trade off to congestion management capability of TCP.

4.1 Video Sending

4.1.1 Flowchart

The flowchart in Figure 4-1 shows the working of the video communication software. Since TCP has been used as the transmission protocol, a TCP listener is used to wait for a request for TCP connection from the remote end. After a request is received, the webcam is initialized. Images can be acquired either in `grab acquire`, for continuous acquisition, or `snap mode`, for capturing image only once. Since a continuous flow of frames is required, `grab acquire` is used. It is done in a continuous while loop till the user requests to stop the program by clicking the "stop" button on the user interface. At the same time, image frames grabbed from the last frame are flattened to string, concatenated with the length of flattened string and then transmitted to the remote end. In LabVIEW, data has to be flattened into string format because TCP write only accepts strings as input. While an image is being capture from webcam, the image that was captured in last frame is flattened.

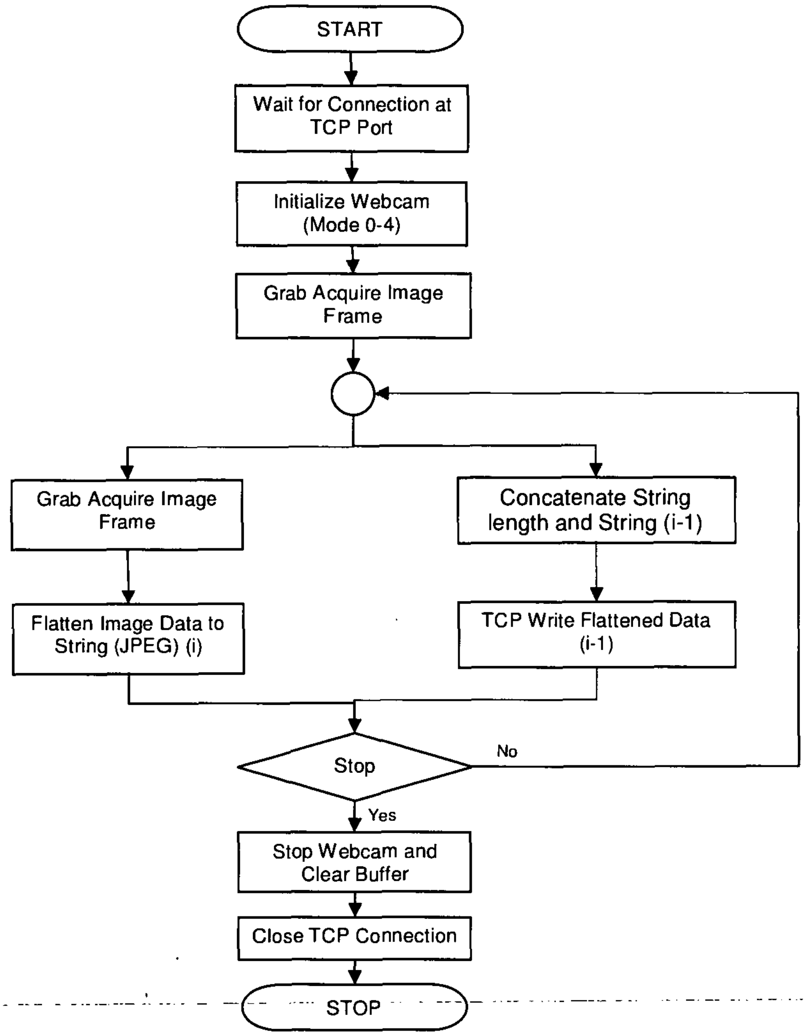


Figure 4-1 Video acquisition from webcam and transmission.doc

4.1.2 VI

The implementation of the flowchart (Figure 4-1) in LabVIEW is shown in Figure 4-2. The VI used in it are described next.

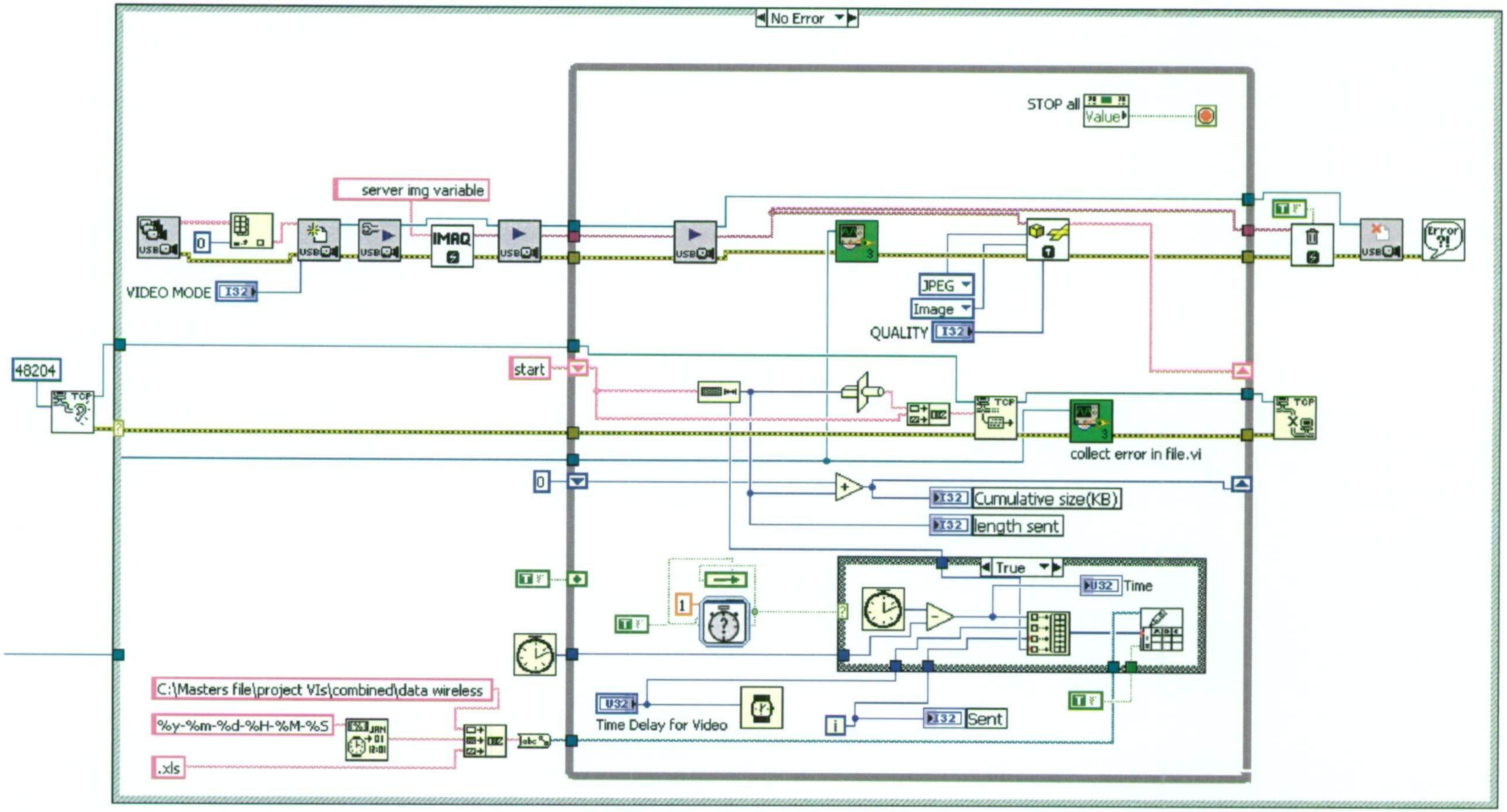


Figure 4-2 Frame acquisition and transmission uses TCP

4.1.3 Description of the program

Video Sending VI is used to start a continuous acquisition and then transferring it to remote computer. The clinician side or the server computer waits for connection request from the client computer. The software is described in following major steps. The steps below are also shown in the flowchart Figure 4-1. A brief description of the sub VIs used are present in the appendix.

Configuring the webcam:

The first step is to initialize the webcam which is done by `IMAQ USB Init`. It needs the name of the webcam to be used. The list can be generated by `IMAQ USB Enumerate cameras`.

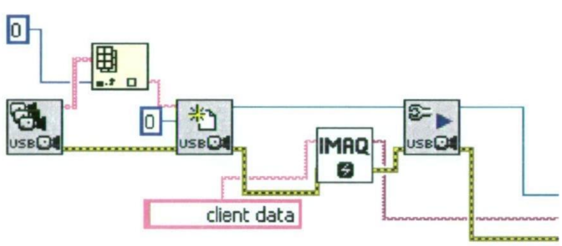


Figure 4-3 Configuration of webcam for image acquisition

Figure 4-3 shows how the webcam is configured. Since the webcam is used in video mode, grab is used. If only one image is to be acquired then `IMAQ USB Snap` is called. Then `IMAQ Grab Acquire` is called to copy images from the continuous acquisition.

TCP Connection:

A connection between the patient and clinician computer is established by `TCP Listen` (Figure 0-8) and `TCP Open Connection` (Figure 0-8). `TCP Listen` runs at the clinician side. It waits for the patient computer to request for connection. `TCP Open Connection` does the connection request.

Capturing frames:

Figure 4-2 shows continuous frame acquisition. `IMAQ USB Grab Acquire` VI acquires an image during a continuous acquisition. It needs an image reference where it can save the image in. `Collect Error in File` collects error in for later analysis.

Flattening and Sending:

This image frame is then compressed as JPEG format and then flattened to string. The length of image data is found by using `String Length`. `String Length` returns a 32 bits integer. This integer is converted to String that is 4 byte long. It is also called type casting.

The length of data and the date itself are concatenated to a single data instead of sending it separately. This concatenated data is then sent to remote end using the `TCP write` VI. The default time out is 25000 sec. This programming uses the inbuilt multithreading feature of LabVIEW. Grabbing frames from the webcam and flattening is done in one thread while concatenating the data from pervious threads and transmitting data to the TCP network connection is done in two parallel threads Figure 4-2. This is also illustrated in the flowchart Figure 4-1.

Saving data for diagnosis purposes:

The length of the string is noted in the numerical indicator. It is also added in the cumulative size indicator. "Sent" records the number of frame sent and Stop button is used to stop the loop. Time Delay for Video 2 is the numerical input to `Wait` VI.

4.2 Video Receiving

4.2.1 Flowchart

The flowchart Figure 4-4 shows the working of the video communication software at the receiving end. A `TCP wait` for connection sub VI is used to request for connection to remote end for TCP connection. The clinician side waits for the patient computer to make a connection request. After the request is accepted, the remote end sends the data. This data is captured by `TCP Read`. `TCP Read` reads data in two stages – first it reads the length of data (flattened image data) and then using the length read, reads the data. So in first step the data length is read and then this data length is used to determine how long the image data is and this data is read again. This flattened data in string format is unflattened into a JPEG frame and then displayed. Since a continuous flow of frames is required, a while loop is used which stops when the user requests to stop the program. The image buffer is cleared and the TCP connection is closed at the end of the program.

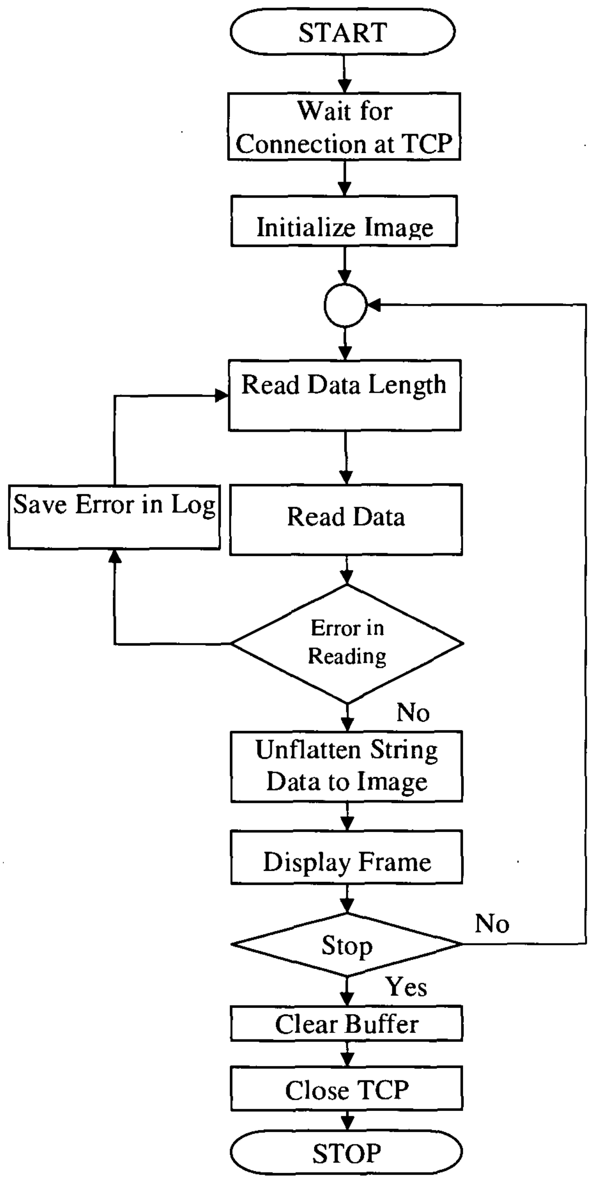


Figure 4-4 Image Frame Receiving and Display

4.2.2 VI

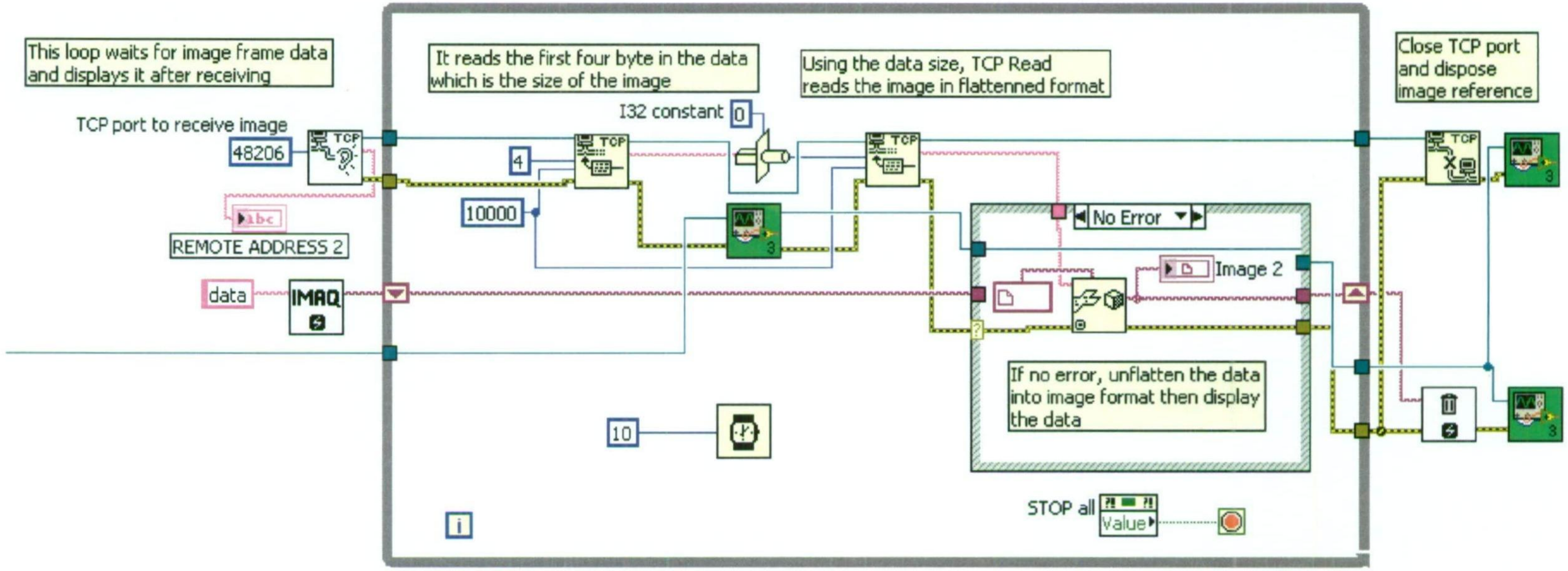


Figure 4-5 Data receiving, unflattening to image data and displaying in monitor

4.2.3 Description of the program

Video receiving and displaying is done is three parts – initialization, receiving data and displaying in the monitor and finally finishing. A brief description of the sub VIs used in this section can be found in the Appendix.

Initialization:

TCP connection is the first part for the video communication. For the TCP connection, server waits for connection request from the client side. `TCP listener` at the server (clinician) side waits for the patient side to request for connection and then waits for video data. Similarly in patient side `TCP Open Connection` requests the server (the clinician side) for connection and waits to receive video data. A reference (Figure 0-3) is created to store the frame data received from the patient side.

Receiving Data:

`TCP Read` reads the data for image frame sent by the client side (patient side). Data are read in two steps – first data read is the size of data (image frame) and second is the data of the image frame itself. The size of image frame is required to read the image frame (Figure 4-5). The image data, which is in string format, is unflattened to image format. It is then displayed on the monitor. In case the delay in reading data is more than 25 seconds, *`TCP Read`* cancels the operation and waits for new one.

Finishing:

The loop stops when "Stop All" button is clicked. When the program comes out of the loop, TCP connection is closed and image reference is disposed off using *`IMAQ Dispose`*.

5 Design of the Audio System

The audio system software has two parts – 'audio acquisition and sending' and audio receiving and playing. Each part is described with the help of a flowchart and VIs. Sub VIs involved are described in the appendix.

The Audio system allows point-to-point, real-time voice communication over the network using UDP (User Datagram Protocol). UDP was chosen because it is faster than TCP. There is an upper limit on what is acceptable for the end-to-end delay in voice conversation. For acceptable communication, the overall delay budget for a one way voice conversation is 125-150 milliseconds[93].

WAV format was used for audio. WAV is the raw audio format without any compression. Combinations of options possible for WAV format are shown in Table 5-1. For example, one can choose 22050 Hz sampling rate at mono quality at 16 bps.

Table 5-1 Parameters for Audio

Sampling Rate (Hz)	Sound Quality	Bits per Sample
8000	Mono	8 bits
11025	Stereo	16 bits
22050		
44100		

The compact Disc (CD) quality is 44.1 KHz, 16 bit. However, 8 bit at 8 KHz is enough to reproduce the sound[30]. The Nyquist–Shannon sampling theorem states that if a signal x(t) with highest frequency of F Hz can be completely reproduced by its ordinates at a series of points spaced 1/(2F) seconds apart [94]. So it can be completely determined by sampling at frequency 2F which is double the frequency of the signal. The frequency band range in telephony is from 300 Hz to 3400 Hz. The bandwidth allocated for a single voice-frequency transmission channel is usually 4 kHz. So a sample rate of 8 kHz is used as the basis of the pulse code modulation system used for the digital PSTN[95]. So 8000 Hz, Mono Sound Quality at 8 bits per sample was chosen. The voice data were transmitted in small segments (packets) of data, each data packet containing about 250 ms of data (2000 bytes).

The inbuilt microphone of the Laptop (Dell Latitude D600) was used as the input device and headphones with 3.5 mm jack as the output device.

5.1 Audio Acquisition and sending

This section describes the concept used in developing the software for sampling the audio data from the microphone and sending it to the remote end over the network. It is followed by a brief and complete description of the program as developed in LabVIEW.

5.1.1 Concept and Flowchart

The audio communication is based on UDP so a UDP port has to be selected. Therefore, the first step is to open a UDP port. The microphone is initialized in the format chosen for the purpose so that it is ready to sample voice data from the user. Using low-level audio functions, audio buffers are allocated to the waveform input device. The audio data are sampled and stored in buffers. The buffer size was chosen small to keep the delay relatively smaller. The data is stored in a shift register. The shift registers, when used inside a loop, store data from the last loop. In the next loop, the data stored in the shift register (shift register stores data from the last loop) is send over the network while new audio data is sampled from the input device. Therefore, the sampling function and data sending are done concurrently. In case of error in sampling, the sound buffer is cleared and a new audio data is cleared. The process has also been shown with the help of flowchart (Figure 5-1).

The above loop continues until the program is stopped using the stop button. The stop button stops the whole program as well. Finally, the UDP port is closed, audio buffer is cleared, microphone is closed freeing the resources.

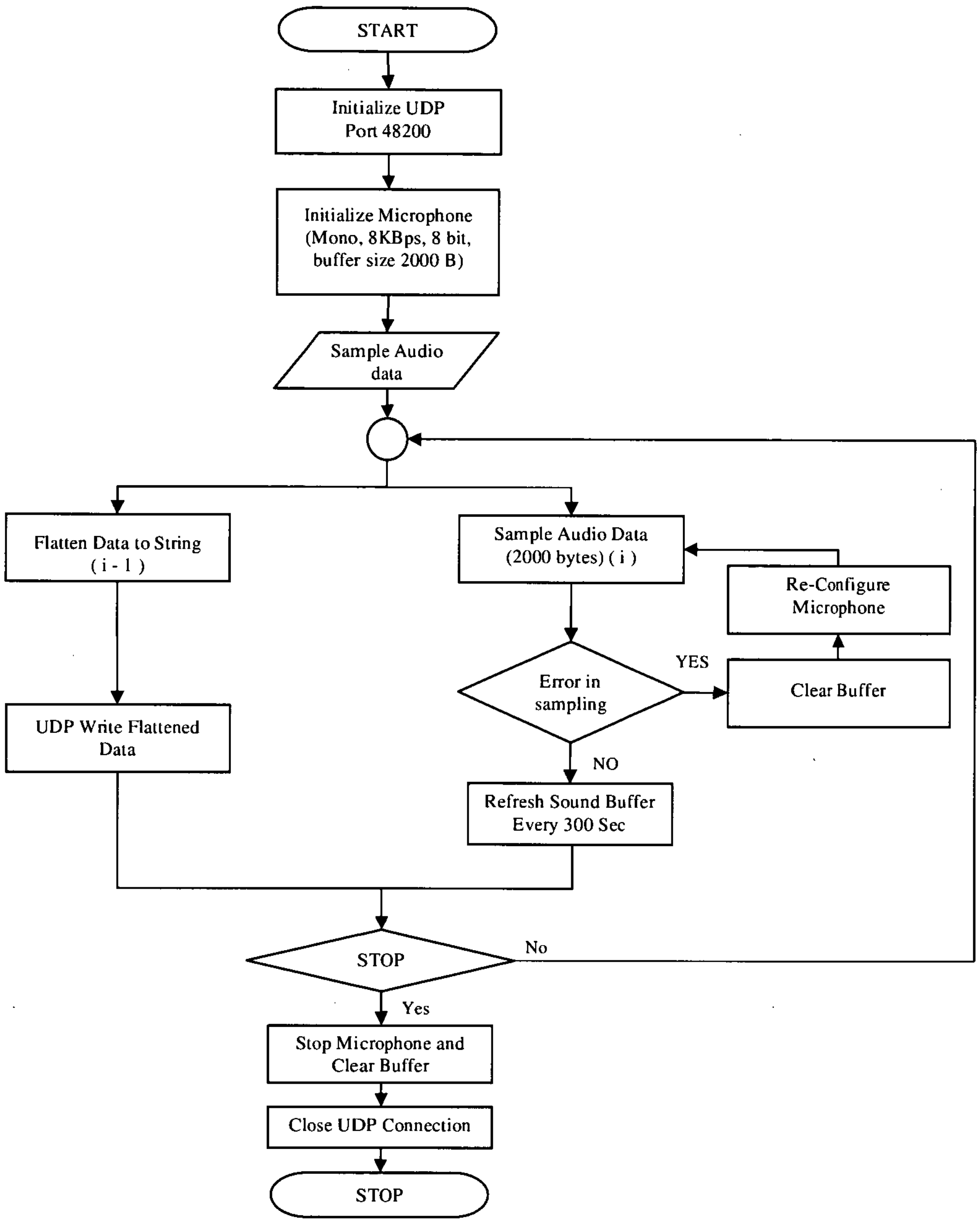


Figure 5-1 Audio acquisition from the microphone and transmission(sending)

5.1.2 Description of the program

This section describes the implementation of the above flowchart in LabVIEW. A brief discussion of the sub-VIs used is listed followed by the description of the program in blocks.

The sub VIs used are as follows.

SI Config

`SI Config` configures the sound input device (Figure 5-2). It also creates a sound output task ID.

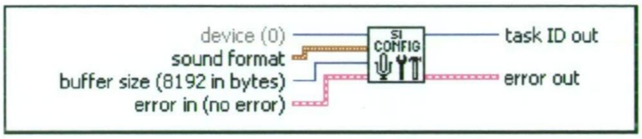


Figure 5-2 SI Config.vi

SI Start

`SI Start` prompts the sound input device to begin accumulating voice data (Figure 5-3).

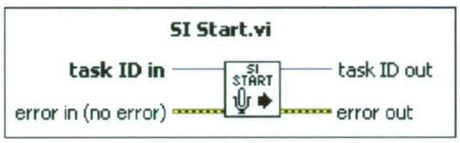


Figure 5-3 SI Start

My SI Read

`My SI Read` reads data form the sound input device (Figure 5-4). If data has arrived to the sound input device, the device returns that data in mono 8-bit format after buffering. Otherwise, the device waits until data arrives.

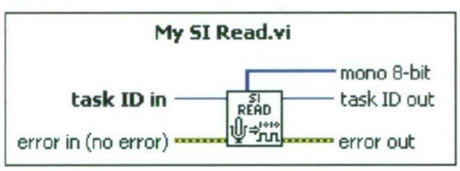


Figure 5-4 My SI Read

SI Stop

`SI Stop` immediately stops the sound output operation associated with the task ID in input parameter (Figure 5-5).

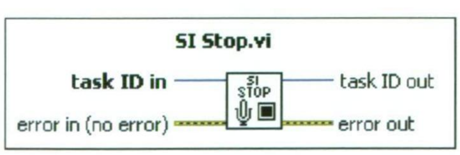


Figure 5-5 SI Stop

SI Clear

`SI Clear` closes the output sound device associated with the task ID in input parameter and releases any resources (Figure 5-6).

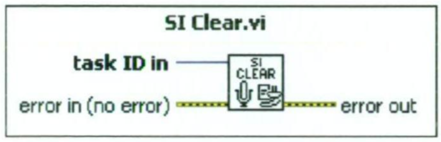


Figure 5-6 SI Clear

UDP Open

`UDP Open` opens a UDP socket on the port or service name (Figure 5-7).

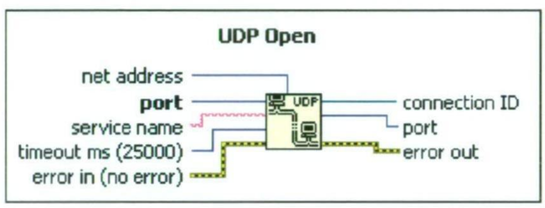
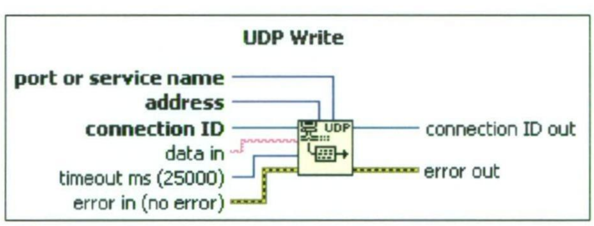


Figure 5-7 UDP Open

UDP Write



`UDP Write` sends the data to the address. The address is one of the inputs to the UDP port (Figure 5-8).

Figure 5-8 UDP Write

UDP Close

`UDP Close` closes the UDP socket opened previously (Figure 5-9).

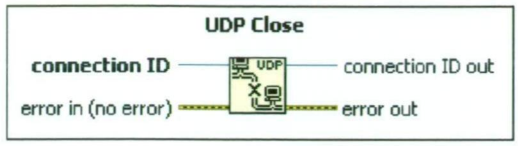


Figure 5-9 UDP Close

Unflatten from String:

`Unflatten from String` is same as unflatten from string described in video communication section (Figure 0-14).

The implementation of the program can be described in the following blocks. The blocks are

5.1.2.1 Setting up Microphone / Configuration

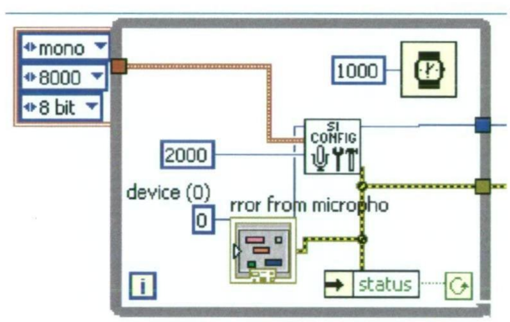


Figure 5-10 Sound Configuration

As mentioned in the introduction of this chapter, the program uses sound configuration as mono type, sample rate of 8000 Hz with 8 bits per sample. This configuration uses minimum bandwidth for audio communication (Figure 5-2). The calculated bandwidth required with this configuration is 64 Kbps.

A cluster with the three values (sound quality, rate and bits per sample) (Figure 5-10) sets the `SI Config` (Figure 5-2). Sound format specifies the set up of sound operation (Mono or Stereo), its playing rate (speed), and bits per sampling - 8 or 16. It has been further explained below.

- Sound quality sets up the sound operation as stereo or mono. Mono has been used in this software.
- Rate sets the sample rate for the sound input operation or the update rate for the output operation. Available options are 8000, 11025, 22050, or 44100 Hz.

- Bits per sample sets up the sound operation for 8 bits or 16 bits for each sample. 8 bits was chosen for the tests.

One of the inputs to `SI config` ("device" - shown as 0 in Figure 5-10) identifies the sound input device if there is more than one microphone connected to the system. Normally it is zero unless two or more microphones are present in the system. Buffer size is the size of the internal buffer used by LabVIEW to transfer data from the input device. Since data has to be read and sent in real time, a relatively small buffer is used. The buffer size used is 2000 bytes, which can store maximum of 250 ms of data at data rata of 8 KBps and each sample is 8 bit (LabVIEW recommends to use a higher buffer if there is an overwrite error).

5.1.2.2 Acquiring Data

`SI START VI` starts sound data acquisition Figure 5-2. It prompts the sound input device to begin accumulating incoming data. If the device is running, calling this VI again has no effect so this is only called once. `SI Read` does the actual data acquisition from the sound input device (microphone) and is called repeatedly which is done by the while loop. It waits until the data has arrived unless the data is already in the device buffer. After reading the data, it is stored in the shift register. Data is stored in the shift register to use it in next loop for transmission over the network.

However, if for some reason the buffered data is overwritten, no data is returned and instead, an overwrite error is reported. Error handling for this is shown in the flowchart (Figure 5-1) with a diamond case "Error in Sampling" and in the VI in Figure 5-11 (no error) and in Figure 5-13 (error). In this case, the software reinitializes the sound input device with the same initial parameters, re-samples the data, and sends the data to the shift register. It also displays the error and stores the error in the sub VI "`Collect error in file`".

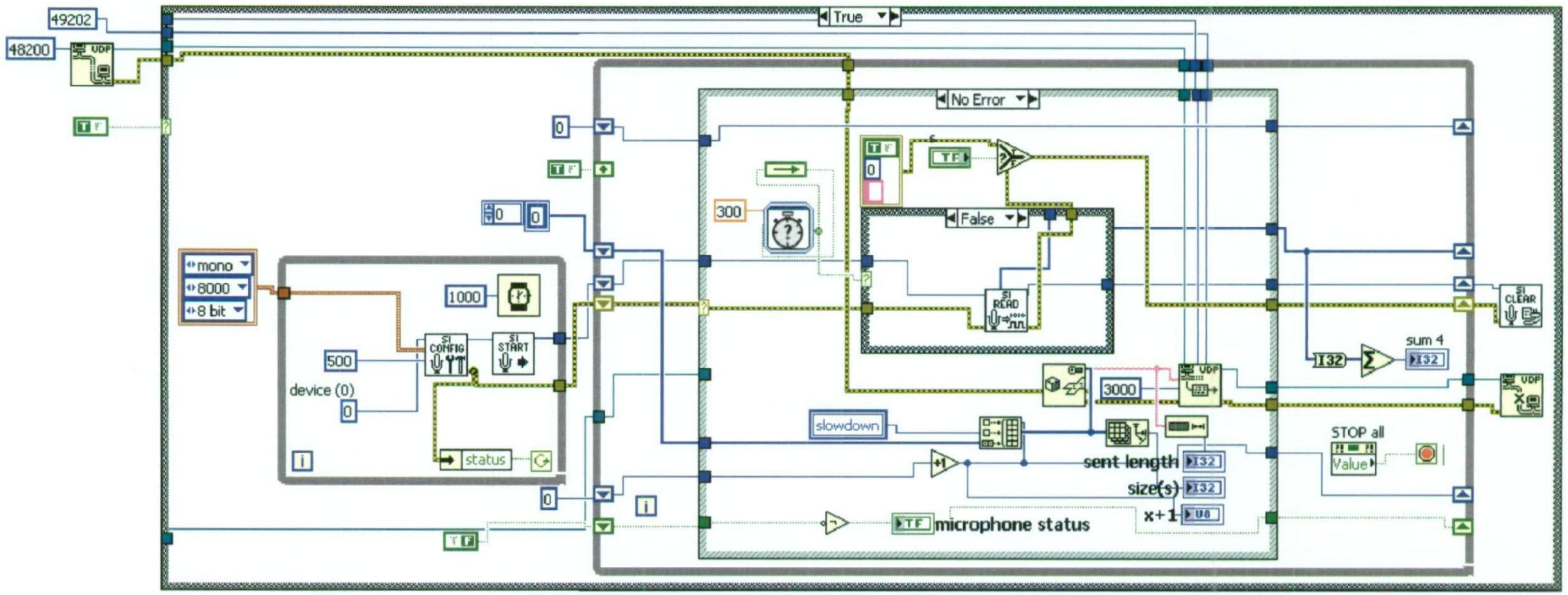


Figure 5-11 Audio acquisition in normal mode

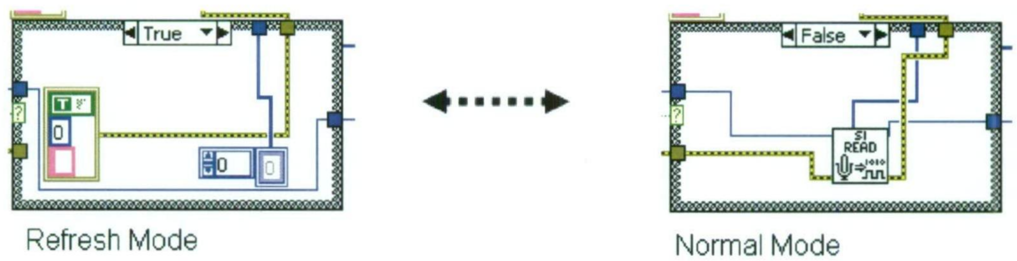


Figure 5-12 Audio acquisition - refresh mode and normal mode

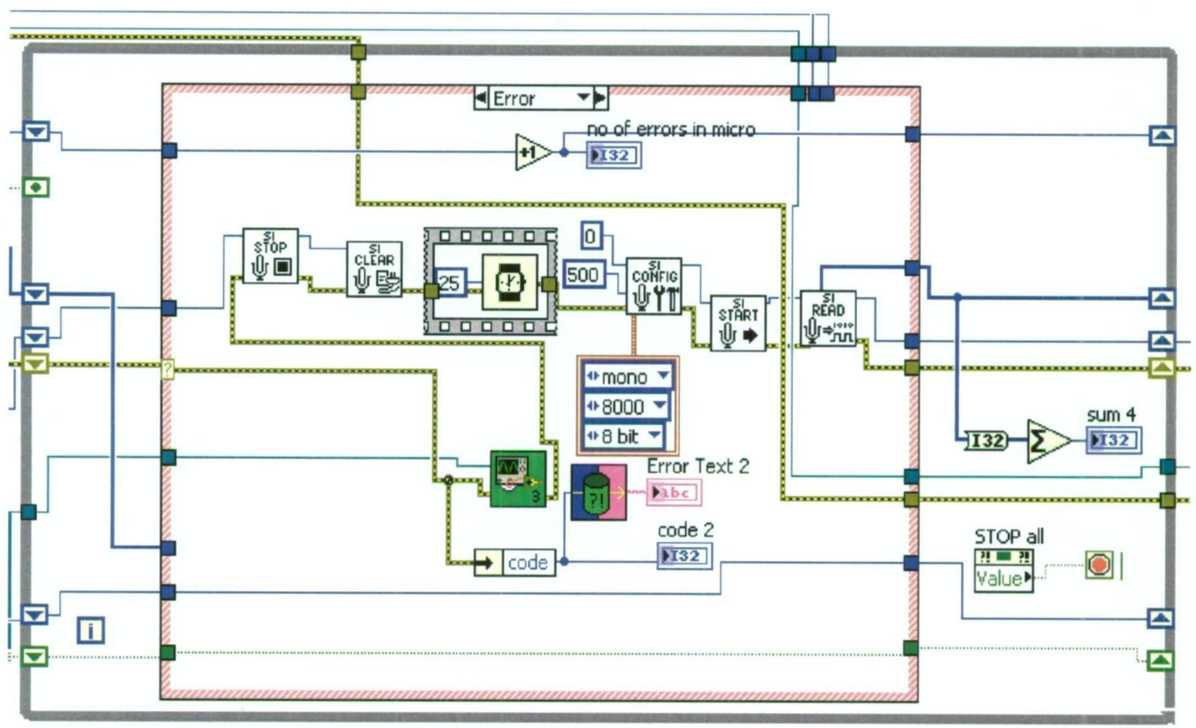


Figure 5-13 Audio acquisition in error mode

5.1.2.3 Sending audio data to the remote end

The sampled data, the output from the `SI READ VI`, from the last iteration is combined with two prefixes, slowdown (intended to be used in future work in managing the bandwidth) and the current frame number. The combined array is then flattened to a string. The flattened string is then sent to the remote computer (host or client) by `UDP Write`. The address of the remote host has to be supplied to `UDP Write`.

Acquiring data from the microcontroller and sending to the remote computer is done concurrently. However, both functions have to end before a new sampling and sending can be done.

5.1.2.4 Diagnosis data

The iteration number of the loop is included with the audio data as the current frame number. The current frame number as mentioned in the last section (Sending audio data to the remote end) is used by the remote end to see if there has been any frame loss. The data acquisition is repeated till the stop button is pressed. The other number is "data slowdown" which is intended to be used in congestion control in future development.

5.1.2.5 Progress Bar

A `Progress Bar` was added in the program as an indicator that the audio acquisition is working. `Progress Bar` is a numeric indicator in the form of bar. The sum of all the values in the array containing sound data is added up and displayed in progress bar (Figure 5-14). Though not an accurate way of representing audio level or intensity, it is useful as an indicator that the software is working and it is getting data from the microphone.

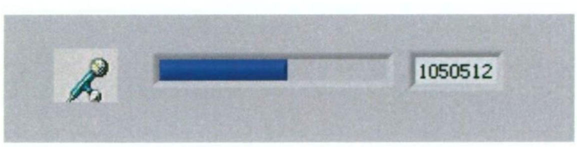


Figure 5-14 Microphone Activity Indicator

5.1.2.6 Ending the loop

There is a local stop button variable that is used to stop the loop and all the loops with multiple copies of stop button.

5.2 Audio Receiving and playing

5.2.1 Concept and Flowchart

In audio data receiving and playing, there are two threads running concurrently – one for audio data receiving and the other for audio data playing to the output device as it is shown in the flowchart in Figure 5-16. In the first thread, which is for receiving audio data, a UDP port is initialized and assigned a number. The UDP port receives data. The data is unflattened from string format to wav format (audio data is in "flattened to string" format) and is stacked into a queue. The queue acts as a buffer. This buffered audio data is then sent to the waveform output device for playback in the second thread. The sound output device is configured as Mono, 8 kHz and 8 bits per sample mode. The buffer size for the output device is set as 2000 bytes. On pressing the "Stop" button, the program closes, frees the UDP port and the output device resources and clears the audio buffer and the queue.

5.2.2 Description of the program

This section describes the implementation of the software to receive and play the audio data. All major sub VIs involved are described followed by how these are used to build the main VI. Sub VIs required for development are as follows.

SO Config

`SO Config` configures a sound device for a sound input operation (Figure 5-15)

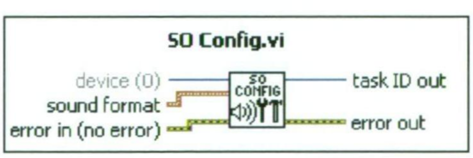


Figure 5-15 SO Config

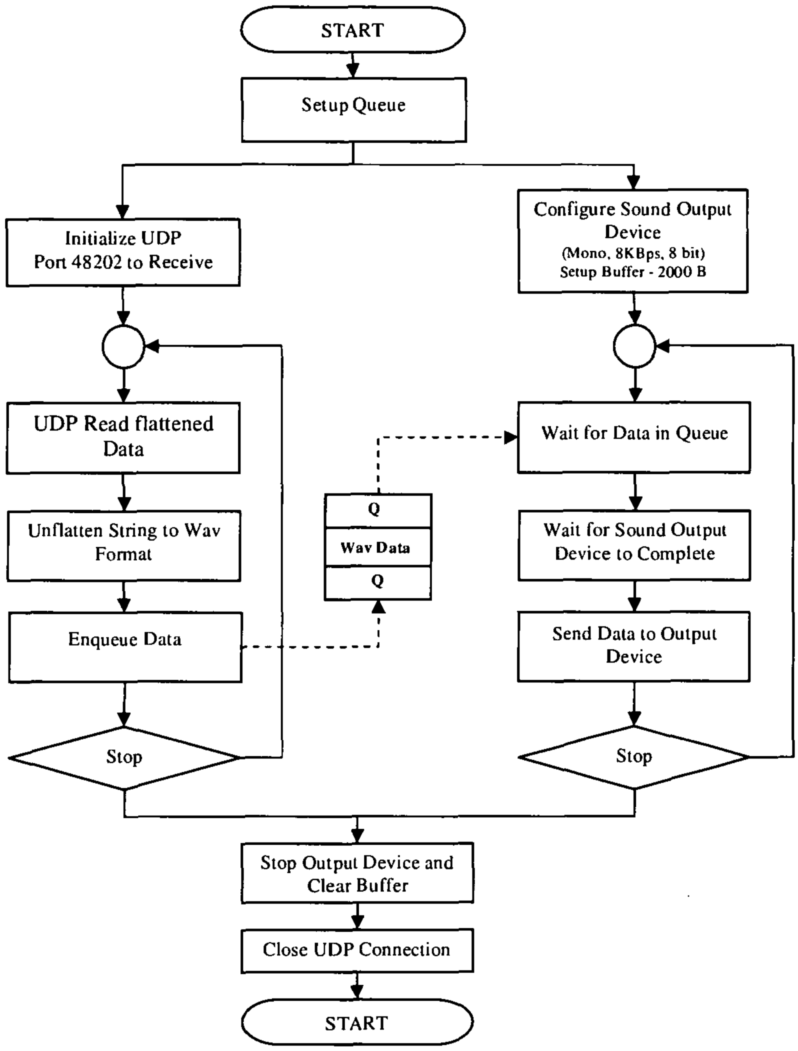


Figure 5-16 Flowchart for audio data receiving and playing

SO Set Num Buffers:

`SO Set Num Buffers` sets the number of output buffers associated with the task ID in input parameter (Figure 5-17). The input number of buffers is set 2000 equal to set buffer for SO Read.

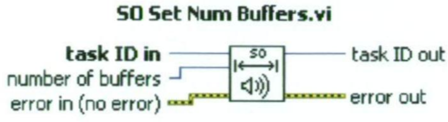


Figure 5-17 SO Set Num Buffers

SO Start:

`SO Start` starts a sound output operation associated with the task ID in input parameter (Figure 5-18).

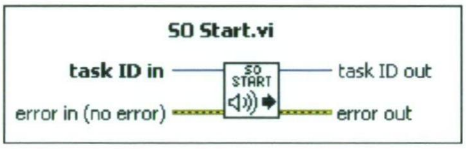


Figure 5-18 SO Start

SO Wait:

`SO Wait` waits until the sound output device finishes playing all the data the device has received (Figure 5-19).

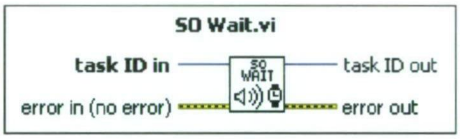


Figure 5-19 SO Wait

SO Write:

`SO Write` writes data to the sound output device associated with the task ID in input parameter (Figure 5-20).

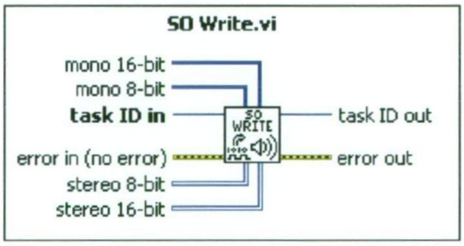


Figure 5-20 SO Write

SO Stop

`SO Stop` immediately stops the sound output operation associated with the task ID in input parameter (Figure 5-21).

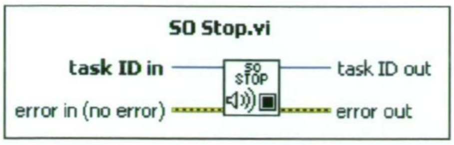


Figure 5-21 SO Stop

SO Clear

`SO Clear` closes the output sound device associated with the task ID in input parameter and releases any resources (Figure 5-22).

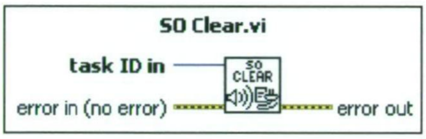


Figure 5-22 SO Clear

Obtain Queue

`Obtain Queue` returns a reference to a queue (Figure 5-23). The reference is an input to enqueue element and dequeue element as described below.

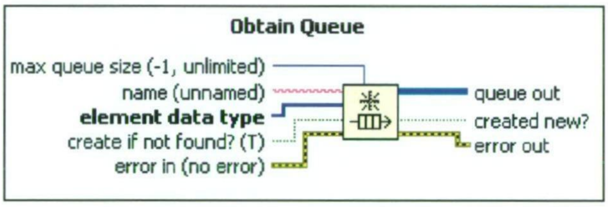


Figure 5-23 Obtain Queue

Enqueue Element

`Enqueue element` adds an element to back of a queue (Figure 5-24).

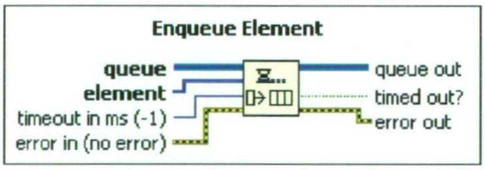


Figure 5-24 Enqueue Element

Dequeue Element

`Dequeue Element` removes an element from the front of a queue and returns the element (Figure 5-25).

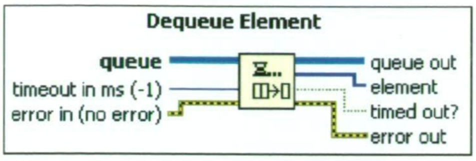


Figure 5-25 Dequeue Element

Get Queue Status

`Get Queue Status` returns information about the current state of a queue, such as the number of elements currently in the queue (Figure 5-26).

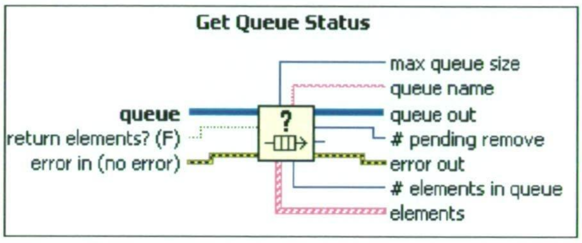


Figure 5-26 Get Queue Status

UDP Read

`UDP Read` reads a datagram from a UDP socket and returns the data in string format (Figure 5-27).

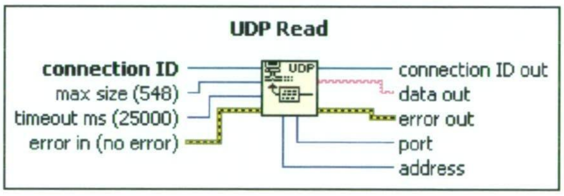


Figure 5-27 UDP Read

The program is described in four major blocks as follow.

5.2.2.1 Sound output setup:

The `SO Config VI` (Figure 5-15) sets up the sound output device. The sound format is the same for both sound input and sound output which is mono, 8000 Hz and 8 bit per sample. Device id is 0 unless there are more than one sound output devices attached with the computer. The buffer is set as 2000, which is done by `SO Set Num Buffers` (Figure 5-17). After setting up the output device (Figure 5-28), the data from the queue is played in a continuous loop (Figure 5-29). It is explained in next section.

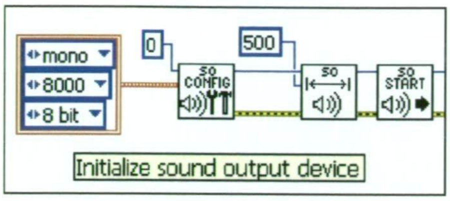


Figure 5-28 Configuring the sound output device

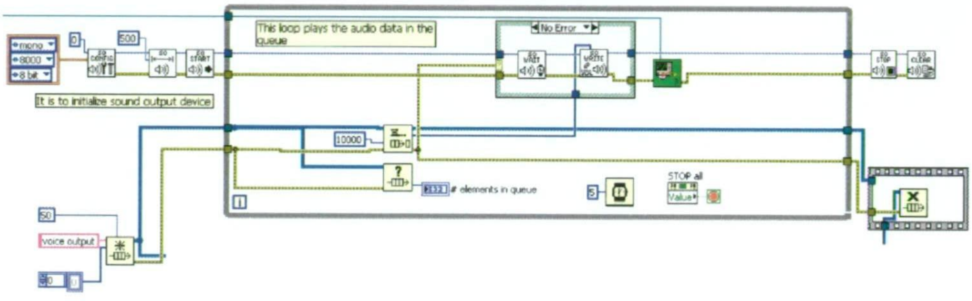


Figure 5-29 Audio Data Playing

5.2.2.2 Read data and queue:

Data read by `UDP Read`, which is the audio data sent from the remote end, is stored in a queue. The read data is stored in the voice output queue (Figure 5-30). The additional data are used for analysing bandwidth.

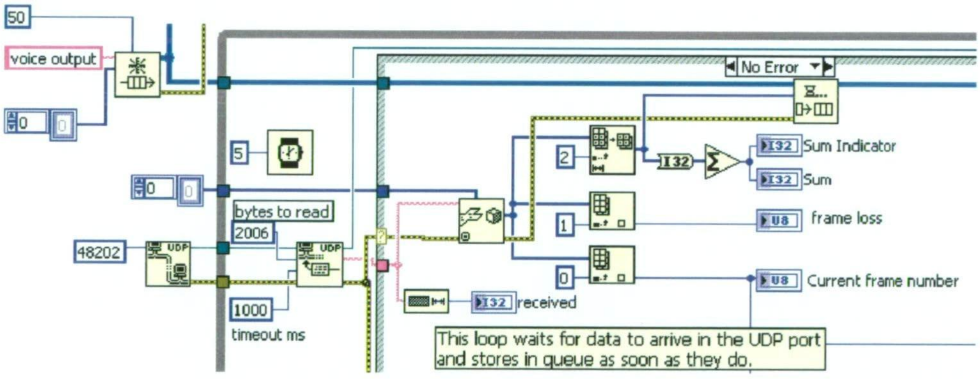


Figure 5-30 Read Data and Queue

5.2.2.3 Playing the sound

The data in the queue is played using `SO Write`. `SO Start` is used to start playing the wav data written to the buffer (Figure 5-29). `SO Wait` VI waits until all sound written to the buffer has been output. It runs continuously in a while loop until the program is stopped. The combination of above two blocks is shown in Figure 5-31.

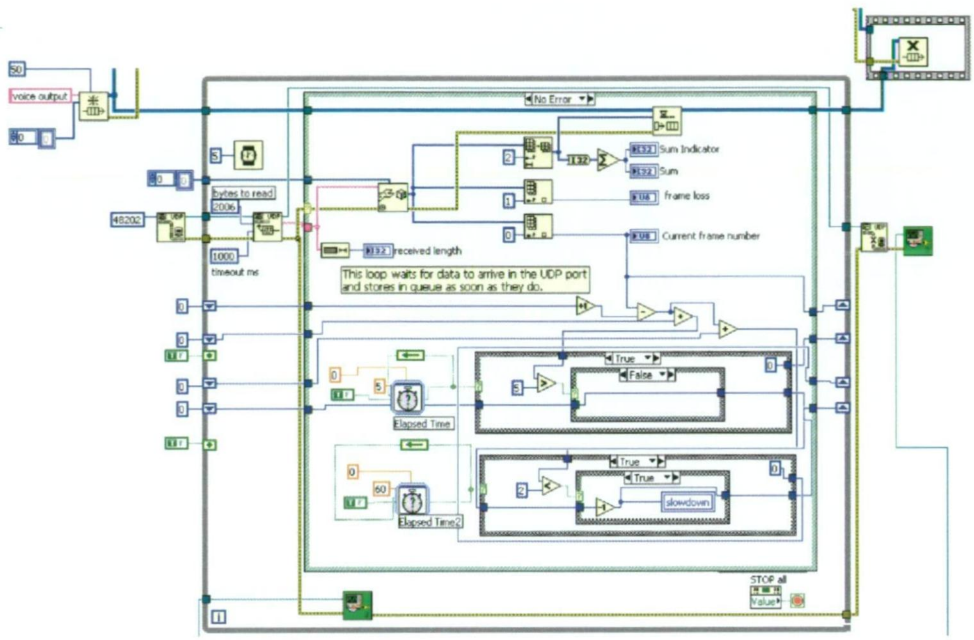


Figure 5-31 Audio Data Receiving

5.2.2.4 Stopping the loop:

The local variable assigned to the stop button stops the while loop mentioned above(5.2.2.3). Once out of the loop `SO Stop` VI stops the sound output operation. `SO Clear` closes the sound output device and releases the resources the device was using back to the computer.

Figure 5-32 shows the final VI, which is combination of above mentioned parts.

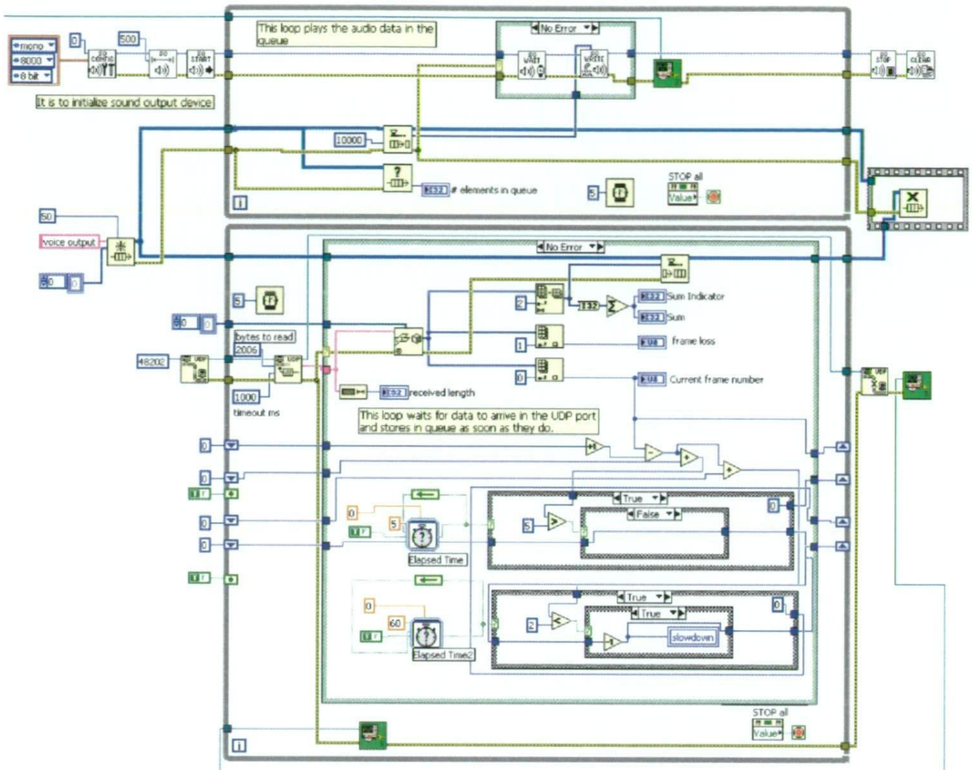


Figure 5-32 Sound receiving and playing

6 Remote Control of the Dispenser

This chapter describes the remote operation of the medication dispenser over the network. The medication dispenser stores the tablets for dosing. It is connected to the patient computer through serial port. The dispensing is controlled by the clinician at the other end. The chapter starts with a brief mechanical description of dispenser. The dispenser was developed as a part of thesis by Ho,V.[96]. It is followed by description of the application design and VI server feature of LabVIEW. The remote control of the dispenser is then described in three parts. The first part describes how the microcontroller is programmed. In the second part, the operation of the dispenser from a computer using LabVIEW is described. The third part describes the remote operation of the dispenser which again uses LabVIEW. Finally the microcontroller program for refilling of the dispenser is explained.

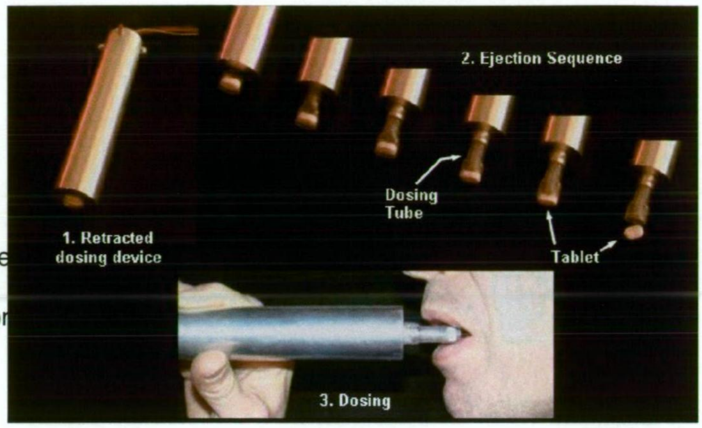
6.1 The medication dispenser (MK2)[96]

The dispenser (Figure 6-1) was developed by the Biomedical Engineering Research Group at the University of Tasmania[96, 97]. The dispenser consists of a (1) linear actuator, (2) a ball plunger holder and push rod unit, (3) a tube holder, and (4) double ended ball plunger and (5) the medication tube. It is completely enclosed in aluminium housing. It also has a push button mounted at the end of the housing. The disposable medication tube holds up to five 8mg, or eight 2 mg, Buprenorphine tablets. A microcontroller is incorporated into the dispenser for control and communication. The microcontroller is a Microchip PIC16F873A and communicates with the computer through RS232 serial port. It has been programmed in Microchip's PICC compiler using C programming language

The functional connections of the major components of the dispenser are shown in Figure 6-2 . The push button is connected to a pin in the microcontroller. It is used to enable the user to control tablet ejection. The linear actuator acts to extend the medication tube out of the housing and also push the push rod to eject the tablets. The system is powered from a USB connection to a PC. In addition, the USB port is configured as a serial COM port, and used for serial communication between the PC and the microcontroller.

Medication is held securely inside the dosing device

The dosing tube holds a single dose in tablet or liquid form.



During dosing, the tube is extended from the housing; the patient places their mouth over the end of the tube. Medication is ejected from the tube into the patient's mouth. Timing of ejection is controlled by the patient using a push-button mounted on the housing.

Figure 6-1 The dispensing process - extension of tube, patient mouth position and tablet ejection, push button controls the timing of ejection

The dispenser is filled with one TAD. The medicine dispenser is operated and controlled by computer and the push button in the dispenser. To load the dispenser, the loader (the pharmacist or the clinician) clicks load button on the software used for dispenser. The medication tube extends out. The medication is loaded manually into the tube. When loading is finished the push button is pressed to retract the tube. Latter versions will have sealing features after loading the tablets for security purposes which has not been implemented in the project now.

In the dispensing process, a dispense button extends the medication tube out to ready position. The clinician has access to the dispense button. However the dispensing itself is controlled by the patient. The push button (Figure 6-2), used in filling the dispenser with tablets, is used to dispense the tablets out. The push button is wired to a digital input on the microcontroller. The status of the button is read in the program. It has to be pressed continuously for the dispensing. There is a time gap between dispensing of two tablets.

The linear actuator has a stroke length of 50 mm and also has an inbuilt potentiometer displacement sensor. The linear actuator has a Home position (the medication tube is enclosed in the cover), a Ready position (the medication tube is in the extended position) and Destination positions corresponding to the position required to eject each tablet.

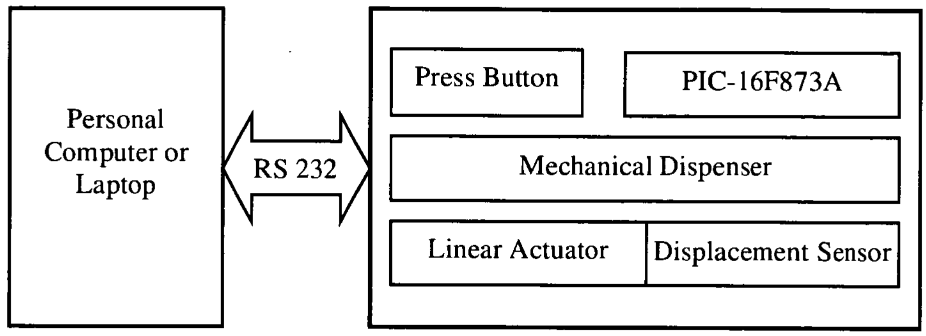


Figure 6-2 Block Diagram of the dispenser with microcontroller, RS232 Connection, Linear Actuator and Displacement Sensor

6.2 Background on software design

This section describes the design of the software for the dispensing system. First the system's software architecture is described. Then the VI server feature of LabVIEW enabling LabVIEW to be run on the patient's PC as a remote application is explained.

6.2.1 Application design patterns: State diagrams

The application design pattern, or software architecture, used in the project is described in this section. An application design pattern is a design to make it software work efficiently and to make it scalable: It is the architecture or programming strategy which determines how the application works. In regard to program flow or the sequence of events in a program, the following two models are possible[98].

a. Independent parallel loop: tasks that need to be done at different speeds or priorities may be implemented in multiple independent while loops that operate in parallel on diagram.

b. State Machine: applications where distinguishable states exist, and each state can lead to one other or multiple states, may be implemented as a state machine.

Since there are a number of easily identifiable states in the remote operation of the dispenser, State Machine architecture is used as the preferred application design pattern in the dispenser system software. State Machine architecture is the functional form of application planning and is one of the fundamental architectures used in building decision making softwares[99, 100]. It is especially used in cases with complex decision making algorithms because the use of the state or the flowchart is easy to follow. As the complexity of applications grows, it also needs relevant adequacy in design. The sequence of event in state diagram is dependant on conditions. State diagrams are first built on paper writing the logic and flow of control. To realize the state diagram, following components are required:

i) While loop: to continually run the different states

ii) Case structure: to contain the different states.

iii) Shift register: to carry the transition of state.

iv) Transition code: to determine the next state to be followed.

A state diagram always starts with an initialize (init) and ends in exit.

6.2.2 VI Server

VI server is central to remote control of the dispenser. VI Server programmatically controls front panel objects, VIs and even LabVIEW itself and can invoke another VI in the same machine or another machine connected by the internet (networked). It can dynamically load, edit, run and document VIs. VI server can change the status of controls and indicators from the remote machine. VI Server can also perform the above mentioned functions across the network wherever the remote machine is located. It uses TCP as the communication protocol. Figure 6-3 shows the sequence of VI server operations. Figure 6-4 shows the block diagram for the VI Server.

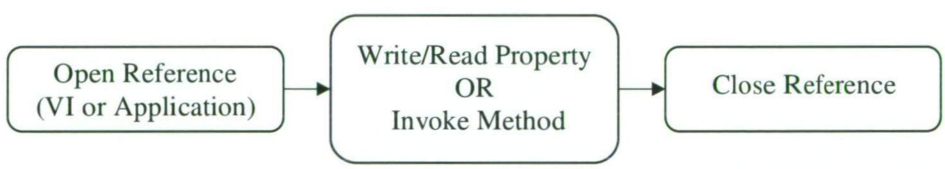


Figure 6-3 Typical VI Server Sequence [100]

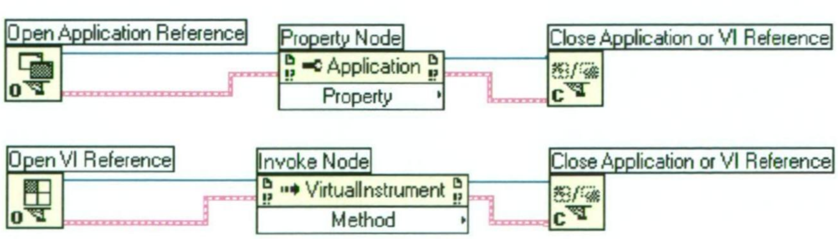


Figure 6-4 Block Diagram of Typical VI Server Sequence[100]

6.3 Concept behind the dispensing system program

The concept behind the dispensing system program is as follows (Figure 6-5). The dispenser is built in with a microcontroller which operates the linear actuator. It is directly connected to the computer (patient side computer) through the serial port. A LabVIEW VI running on the computer controls the dispenser by sending commands to the microcontroller. The commands are in ASCII characters form. The microcontroller is programmed to respond to the commands sent. When finished, the microcontroller sends feedback to the VI. The VI has a user interface to send commands to the microcontroller. However, the user interface is hidden and is remotely controlled by a LabVIEW VI running on the computer at the clinician's end. This is done using VI Server running on the Clinician's computer.

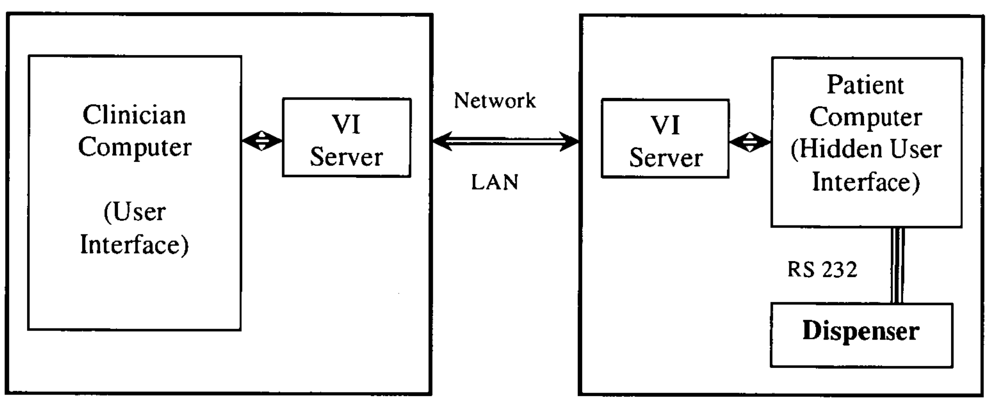


Figure 6-5 Block diagram of the remote control of dispenser by VI Server

In the next section, it is shown how the microcontroller responds to different commands. It is followed by description of the VI that runs on the client (patient) computer. Finally, the VI server that runs to remotely control the client (patient) side VI is described.

6.4 Microcontroller program

This section describes the microcontroller programming. The Microcontroller is the brain of the dispenser. It has following functions:

a. It reads the ASCII character send by the computer.

b. It controls the dispenser by controlling the linear actuator and performs the dispensing action.

c. It reads the output of the displacement sensor which returns the position of the linear actuator.

d. It returns feedback to computer in ASCII character format

e. It also stores and returns the number of tablet stored in the tablet from the microcontroller's flash memory.

The microcontroller program has one main loop with three subroutines – `Dispense_Tablets`, `Query_Tablets` and `Refill_Dispenser`. These three are the main tasks that the microcontroller does. It is shown in Figure 6-6 along with the supporting subroutines. The command from the computer signals which subroutine to execute. The commands from the computer are in ASCII format (Table 6-1).

The microcontroller program has following subroutines (Figure 6-6)

1. Main
2. Refill_Dispenser
3. Dispense_Tablets
4. Query_Tablets
5. Dispenser_Ready
6. Move_To_Destination
7. Leave_Button_Wait
8. Retract_Dispenser
9. Sci_PutByte
10. adc_read
11. read_eeprom
12. write_eeprom
13. SetUpPic
14. Interrupt

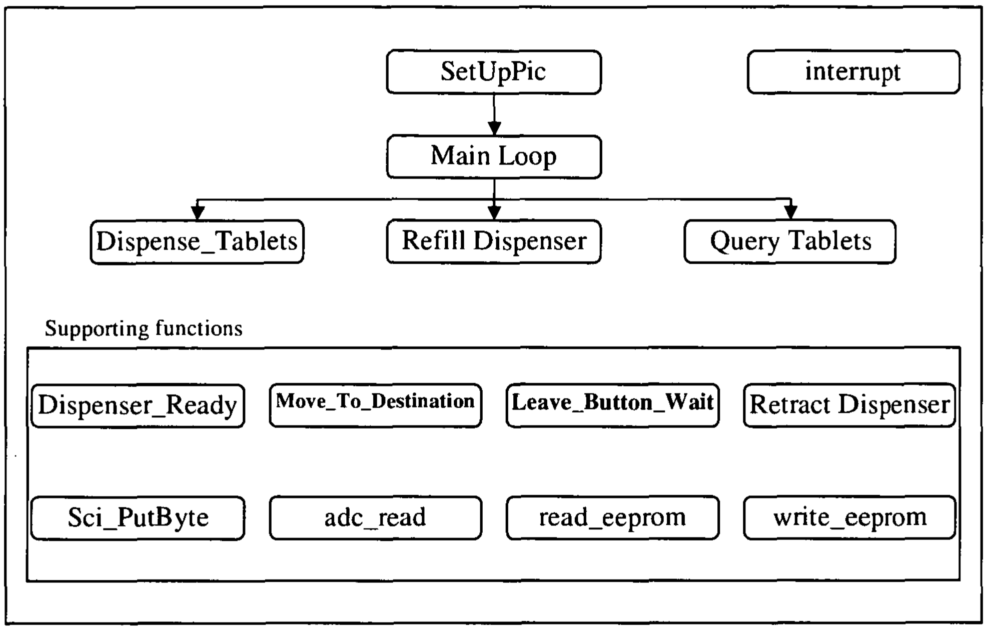


Figure 6-6 The subroutines in the microcontroller program and the hierarchy

A single ASCII character is used either as a command (to dispenser) or as a feedback. Since a single ASCII character is 8 bit, we can have 256 commands and feedbacks values. Not all of them are used. The ASCII values used are shown in Table 6-1.

Table 6-1 List of ASCII characters received and sent by the dispenser's micro-controller

No	ASCII Char	ASCII Val	Interpretation	Type
1.	A	0x41	dispense	command
2.	G	0x47	query no of tablets	command
3.	Z	0x5A	1	feedback
4.	Y	0x59	2	feedback
5.	X	0x58	3	feedback
6.	W	0x57	error	feedback
7.	V	0x56	4	feedback

8.	U	0x55	5	feedback
9.	R	0x52	refill dispenser	command
10.	O	0x4F	refilled 1 tablet	feedback
11.	N	0x4E	refilled 2 tablet	feedback
12.	M	0x4D	refilled 3 tablet	feedback
13.	L	0x4C	refilled 4 tablet	feedback
14.	K	0x4B	refilled 5 tablet	feedback
15.	P	0x50	error	feedback
16.	C	0x43	acknowledge	feedback
17.	E	0x45	Emergency Exit	command
18.	F	0x46	Retract Dispenser	command
19.	B	0x42	Fully Extend	command

6.4.1 Main loop

The microcontroller responds to three commands 'A', 'G' or 'R' (Table 6-1) which correspond to the three functions `Dispense_Tablets`, `Query_Tablets` and `Refill_Dispenser` respectively (Figure 6-7) . The main microcontroller program starts by initializing the microcontroller variables and then reads the flash memory (data EEPROM) at location 0x01, which corresponds to the number of tablets stored in the dispenser. This number is written in the microcontroller's flash memory while refilling the dispenser.

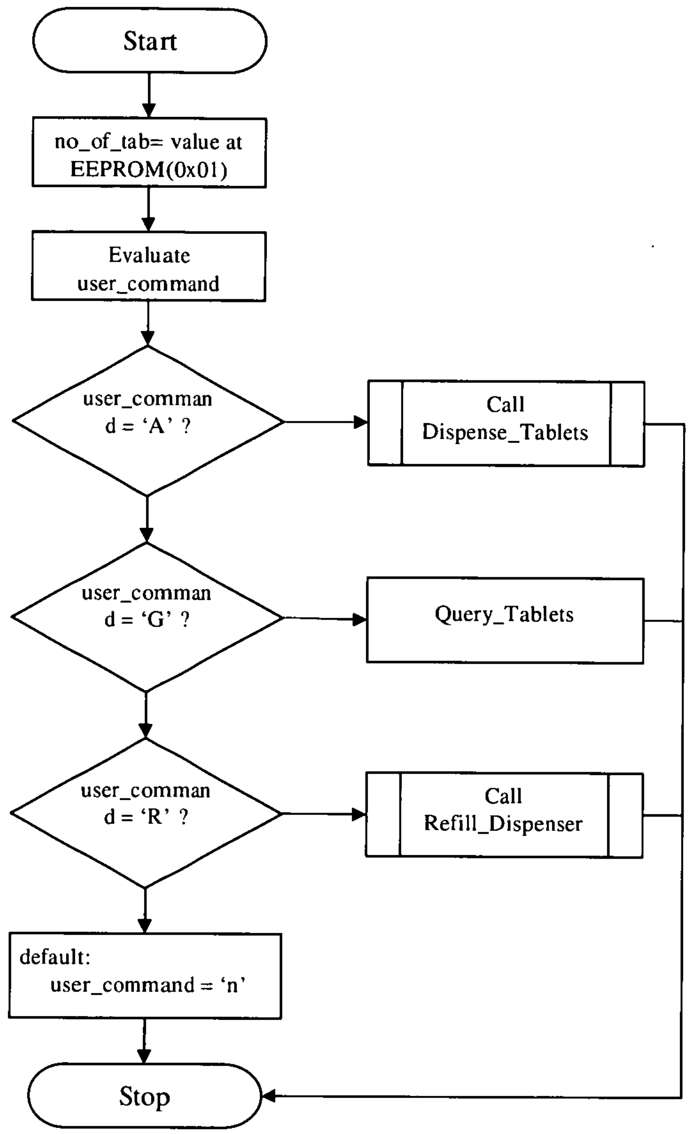


Figure 6-7 Main program that runs on the microcontroller

6.4.2 Dispense tablets:

The subroutine `Dispense_Tablets` dispenses all the tablets in the dispenser (Figure 6-8). The number of tablets in the dispenser is saved in flash memory (data EEPROM) while refilling. This number represents the number of tablets N.

As shown in flowchart Figure 6-8, depending on the number of tablets stored, the dispenser moves to the corresponding position from where the dispenser can dispense the first tablet. After dispensing the first tablet, it continues to push the rest of the tablets. If, for example, the number of tablets are five, the dispenser moves to the position such that it dispenses the fifth tablet and continues to push remaining tablets one at a time. There is a pause of around 200 ms between dispensing of two tablets. If in the push button is pressed in the pause period, the counter for the pause resets and the pause period restarts. The purpose of this pause is to give the patient time to adjust the position of the dispenser. Subroutines *adc_read*, *wait* and *destination* are explained in next section.

Subroutine adc_read

`adc_read` is used to perform an analog to digital converter enabling the microcontroller to digitally sample the output from the (analog) displacement sensor. It is the normal ADC function except that the position is read 10 times and then averaged. The position is read 10 times to average out any inaccuracy in reading.

Subroutine Destination

Calling subroutine `Destination` moves the linear actuator to the position indicated by pos parameter. The push button on the dispenser has to be pressed continuously for the dispense action. When the push button is pressed, it is as read as 1 by the program. As can be seen in the flowchart Figure 6-9, as soon as button1, which is the input from the push button, is zero (which means it is released) the dispenser stops (Move_Stop).

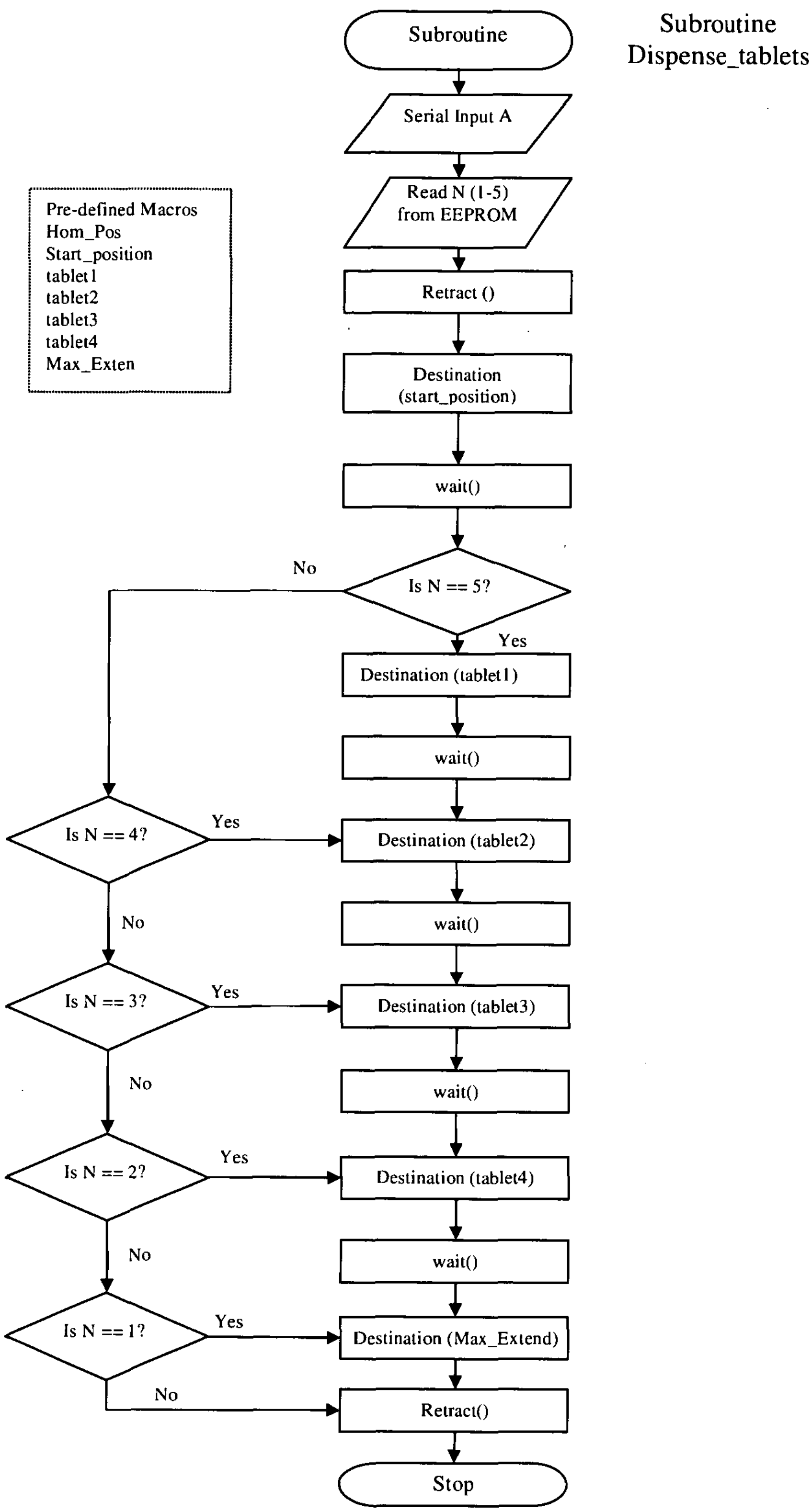


Figure 6-8 Subroutine Dispense_Tablets to dispense tablets from the device

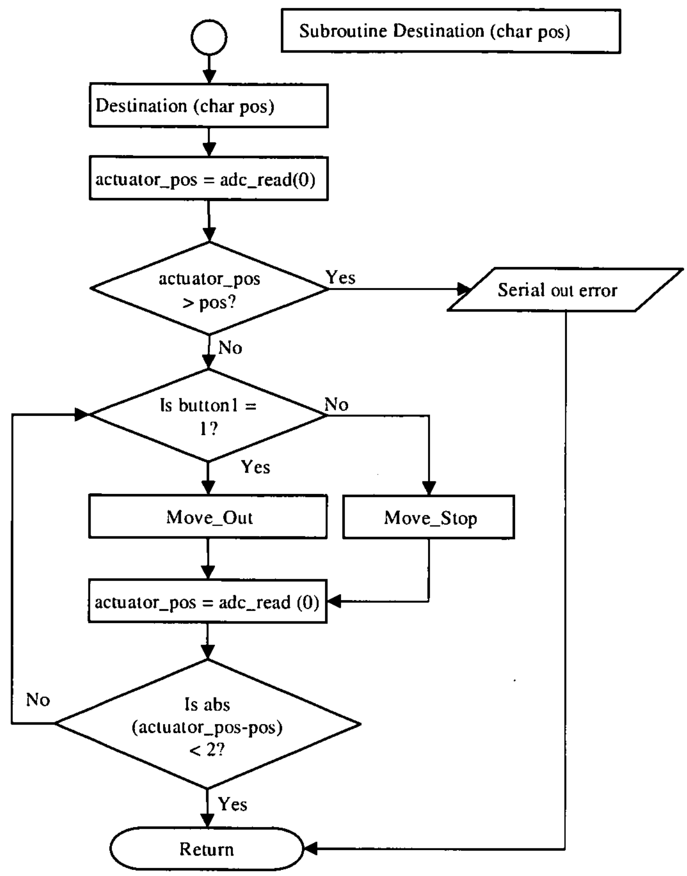


Figure 6-9 Subroutine Destination

Subroutine wait

Subroutine `wait` (Figure 6-10) works as a delay, however, unlike the normal delay loop the delay has to have button1 in the dispenser pressed all the time. The button has to be pressed for fraction of a second for this subroutine to complete. It avoids any accidental pressing of the button leading to next stages.

Subroutine retract dispenser

`Retract dispenser` subroutine retracts the medication tube and the dispenser to the home position (home_pos). Home position means the dispensing tube is inside the aluminium housing.

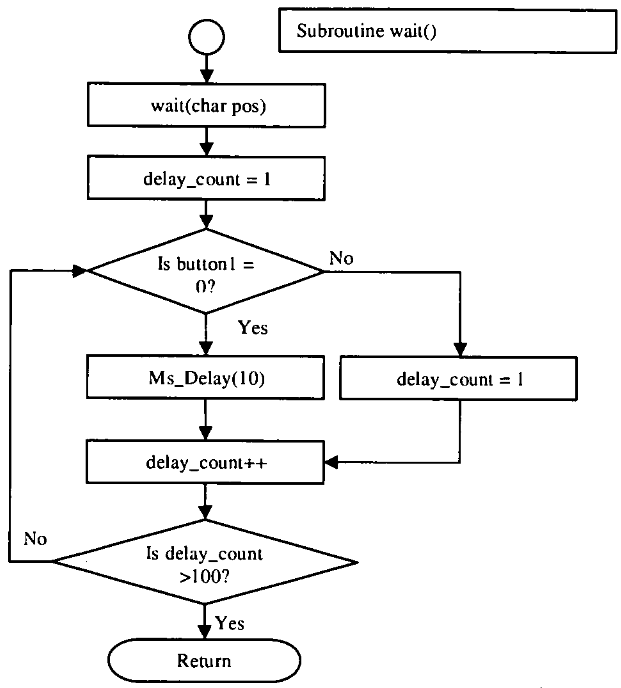


Figure 6-10 Subroutine wait

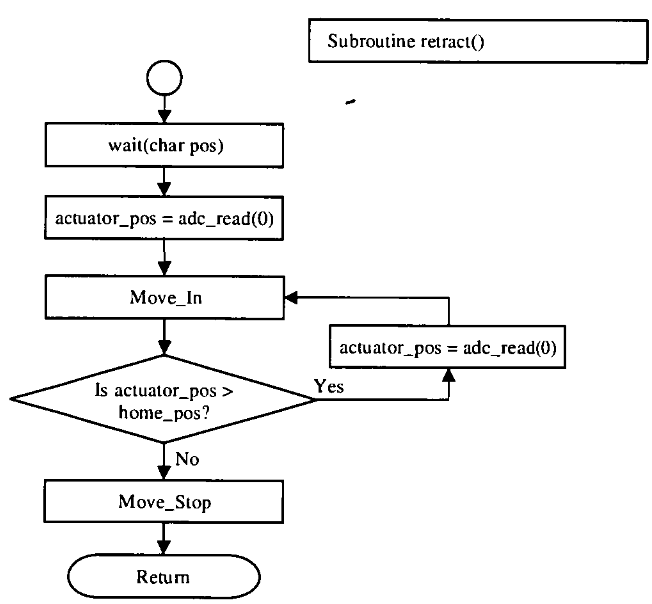


Figure 6-11 Subroutine retract retracts the dispenser to Home Position

6.4.3 Query number of tablets:

`Query_Tablets` is one of the switch cases in the main program (Figure 6-7). It is used to find number of tablets in the dispenser as stored in the data EEPROM of the microcontroller. This switch case is selected when the microcontroller receives ASCII character 'G' from the computer. The microcontroller is programmed to recognize it as a command and in response microcontroller sends three different ASCII character 'Z', 'Y', 'X', 'V' and 'V' representing numbers from 1 to 5 respectively.

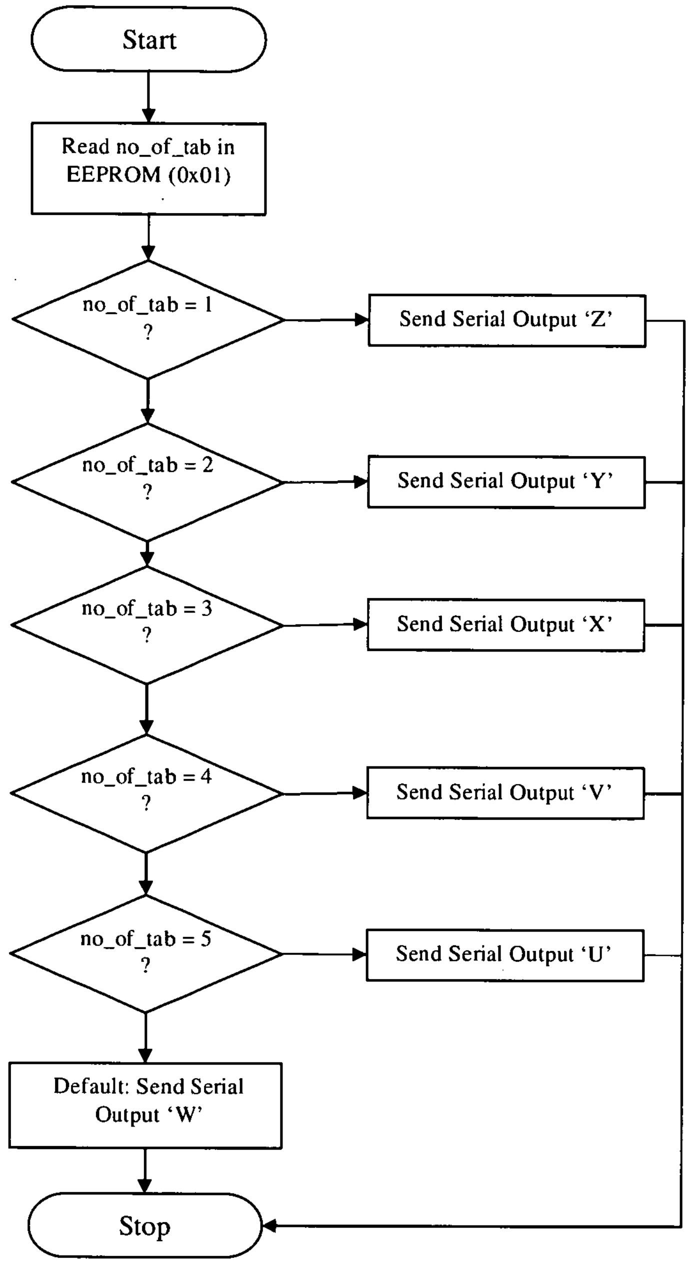


Figure 6-12 Serial Output no of tablets

6.5 Control of dispenser at the client end:

This section describes the VI running on the patient's computer that enables communication and control of the dispenser with the dispenser connected directly to the computer. The interface is shown in Figure 6-13. However, this interface is hidden because the patient is not given access to control the dispenser. This VI is controlled remotely by VI server.

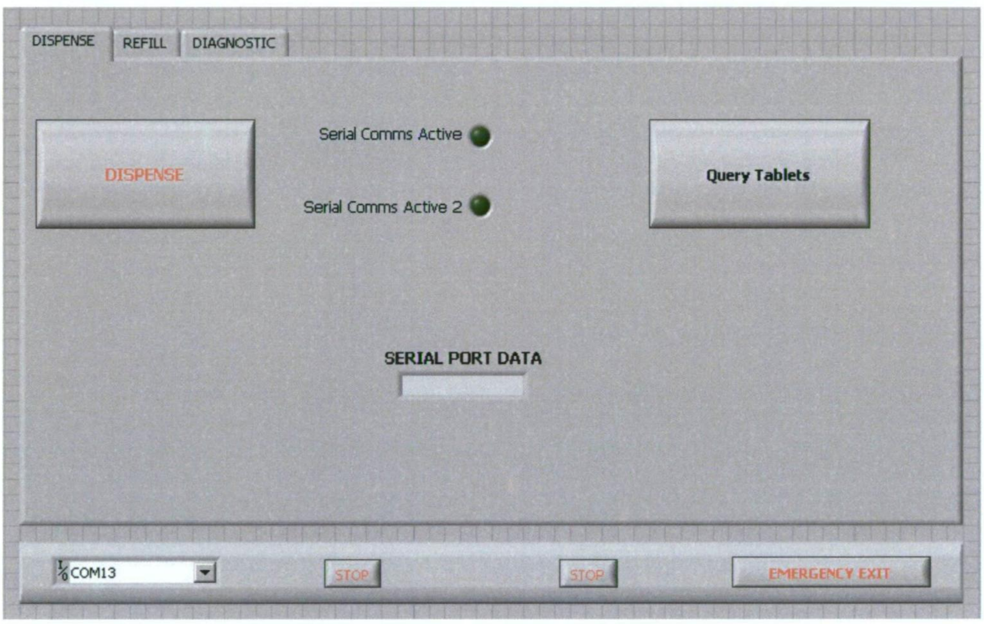


Figure 6-13 Interface to Control Dispenser Locally

The VI basically has two actions.

1. Dispense Tablets: It dispenses the tablets in the dispenser.
2. Query Tablets: It returns the number of tablets loaded in the dispenser. While refilling the tablets, the loader (pharmacist or the clinician) has to enter the number of tablets into the program. This number is written in the microcontroller's flash memory (data EEPROM).

The program has following parts.

6.5.1 Initializing the program

Figure 6-14 is for initializing the serial port. VISA Configure Serial Port initializes the serial port specified by VISA resource name to the specified settings. VISA is a standard I/O API for instrumentation programming. Other input parameters are Enable Termination Char as True, baud rate is 9600, data bits is 8, parity is none, stop bits is 1, flow control is none and time out is 10 seconds. The values are set by default.

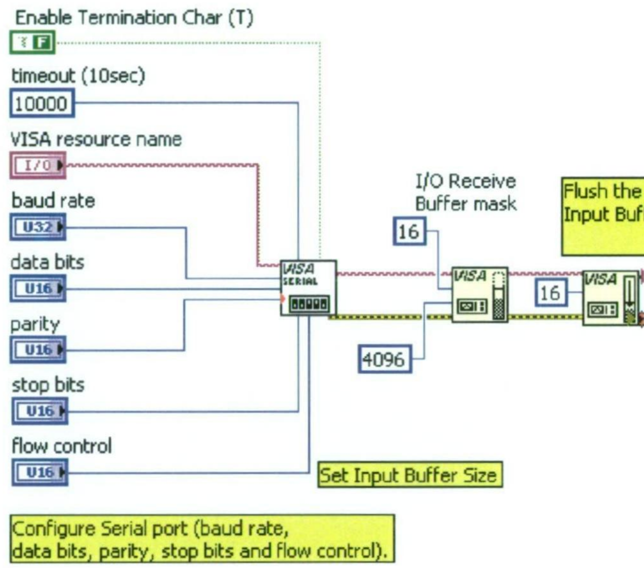


Figure 6-14 Configuring Serial Port

6.5.2 Sending the command

There are three commands that the program sends to microcontroller - E, G, A which are interpreted as emergency stop, return number of tablets in the dispenser stored in the EEPROM and dispense respectively (Table 6-1). The application design pattern used is an independent parallel loop (Figure 6-15).

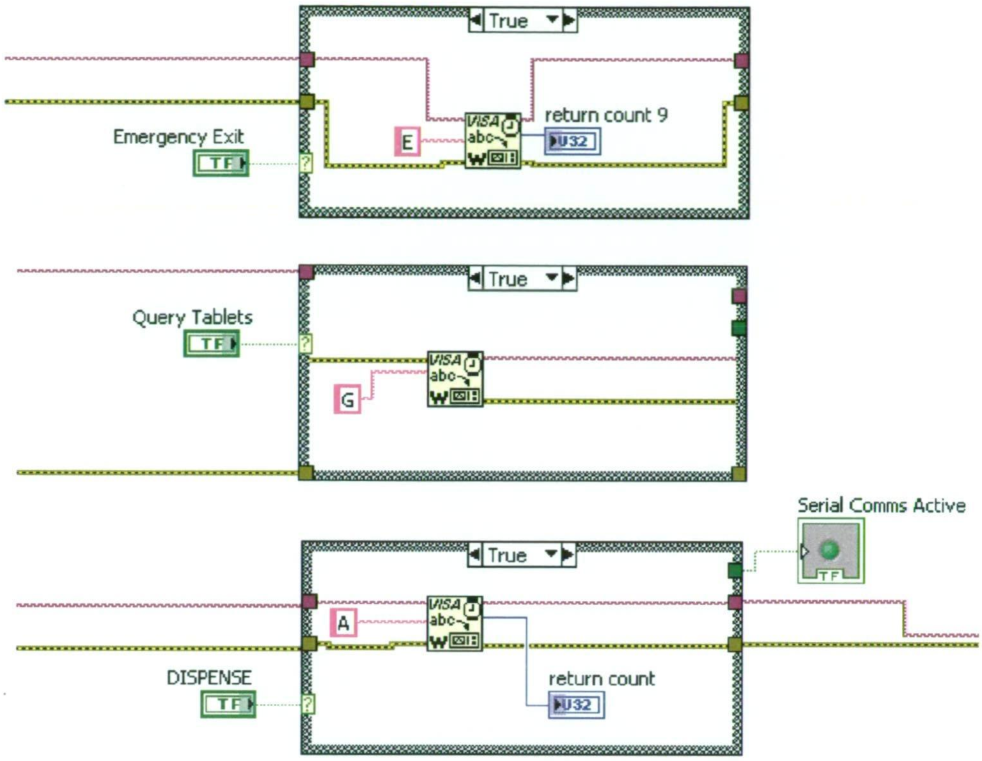


Figure 6-15 Block diagram sending various commands to micro-controller

6.5.3 Receiving feedback from the microcontroller

The last section mentioned how commands are sent using parallel loops. Again, parallel loops are used to receive serial data (Figure 6-16). A delay of 200 ms is inserted to keep it from hogging CPU time when nothing is happening. 100 ms or 200 ms is the human threshold of perception. The microcontroller sends four ASCII characters – 0, X, Y and Z (Table 6-1) under feedback. They are interpreted by the VI as 0,3,2,1 respectively.

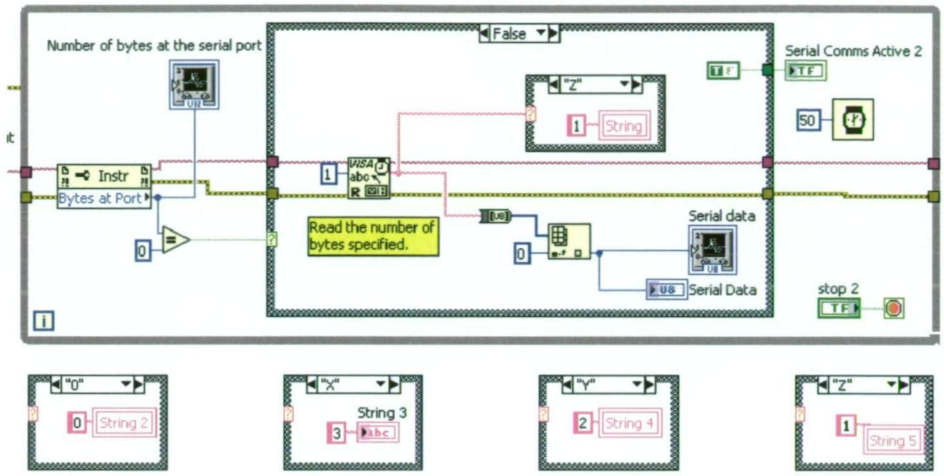


Figure 6-16 Receiving and interpreting data from serial port

6.5.4 Emergency exit:

Emergency exit means there has been some unexpected result. If the microcontroller receives a command ASCII command 'E', it stops the movement of the tube and goes into an infinite while loop which effectively halts the program. The microcontroller has to be rebooted once the emergency exit button is pressed.

6.6 Controlling the dispenser from the remote end

This section describes how the dispenser is operated remotely by invoking the functions described above from the clinician's end.

The user-interface as the clinician sees is shown in Figure 6-17. The button QUERY TABLETS is to find how many tablets the dispenser contains. To start the dispensing process there is a START button on the user interface. CAPTURE button is used to capture the image frame as received from the patient end. EMERGENCY EXIT button is to stop the dispenser at the point of operation. EXIT DISPENSER stops the program at the patient's end. STOP is for stopping the program.

A state diagram has been used as the application design pattern to implement the above mentioned functions. Figure 6-18 shows the state diagram that was used. The design has following states:

a. Initialize:

b. Check Status:

c. Dispense:

d. Query tablets:

e. Emergency Exit:

f. Error:

g. Exit:

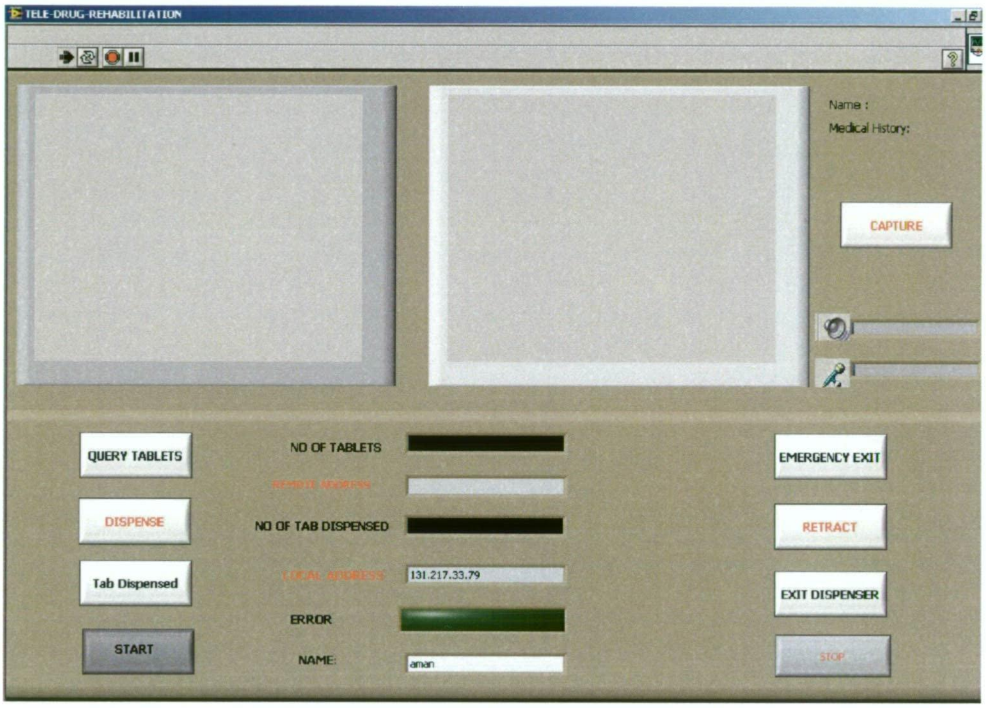


Figure 6-17 User Interface as the Clinician sees

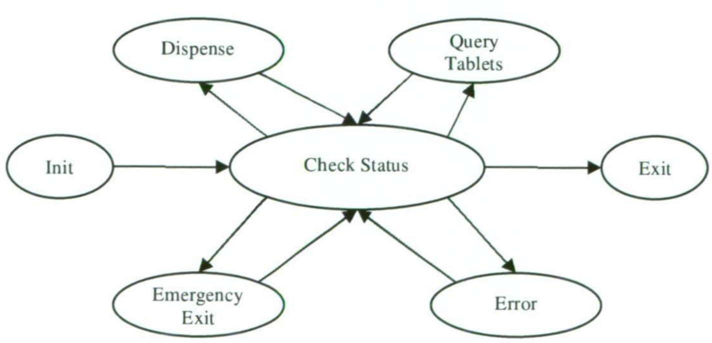


Figure 6-18 State diagram for controlling the dispenser remotely

The VI Server feature of LabVIEW is used. In order to create a VI Server session, an Application Reference and a VI Reference to remote computers (the client machine) are opened. With the VI Reference one can perform actions with the VI like setting or retrieving control values, running it or setting and retrieving the VI's properties. It has been further described in the next section under sub VIs.

6.6.1 Important sub VIs used in the program:

Important sub VIs used are as follow.

Open Application Reference

It returns a reference to a VI Server application running on the specified computer. The machine name is the internet protocol (IP) number of the remote machine (client machine). The VI attempts to establish connection with a remote VI Server on that machine on the specified port (Figure 6-19).

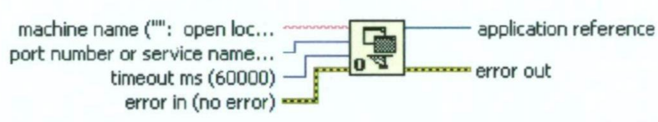


Figure 6-19 Open Application Reference

Open VI Reference:

Open VI Reference returns a reference to a VI in a particular computer. This particular computer is referred to by the application reference obtained from the "Open Application Reference" function. This reference number is a distinctive number that identifies the VI invoked. The reference number is relevant until the program ends. This reference is used by the clinician computer to call the patient program and to control the dispenser as explained in coming sections.

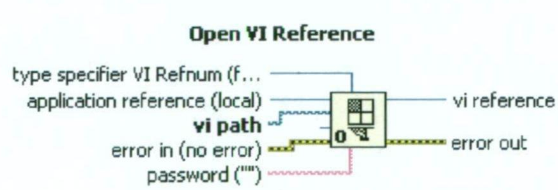


Figure 6-20 Open VI Reference

Invoke Node:

Invoke node is used to invoke a method or action on the remote VI. Invoke node is used in each state except Initialize to remotely operate the dispenser. It has been explained under each state.

6.6.2 The States:

There are seven states in total. They are as follow:

Initialize

This state is used for initializing variables.

Check Status

Check status is the intermediate state between any two states (Figure 6-21). It waits for the user to input some command. In every loop the state compares the output of the four buttons as true or false and the first one to be true is the next step to be followed or else "Check Status" state follows again.

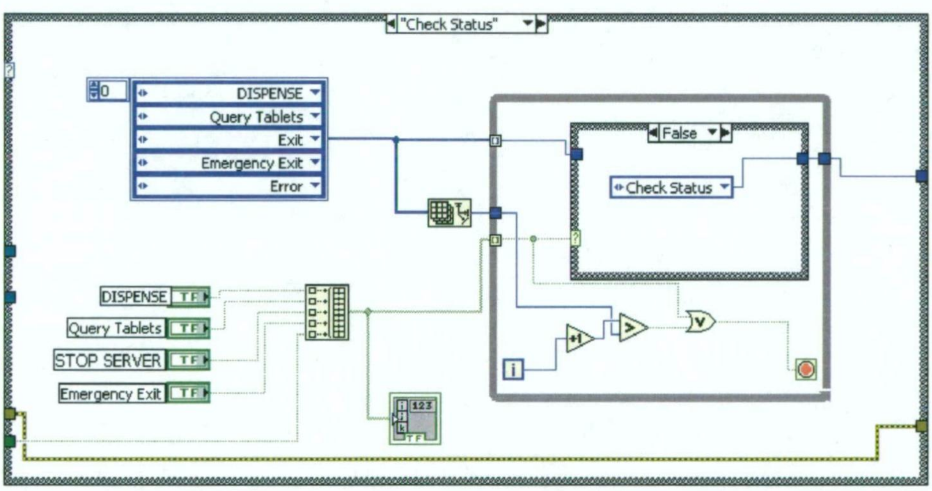


Figure 6-21 Check status state

Dispense State

It is used for commanding the remote dispenser to dispense the tablets in the dispenser. Dispense is the control name at the remote end and boolean true is the required command which has to be flattened. The invoke node has the VI at the remote machine as a reference, so it activates the remote end VI named dispense with the value supplied.

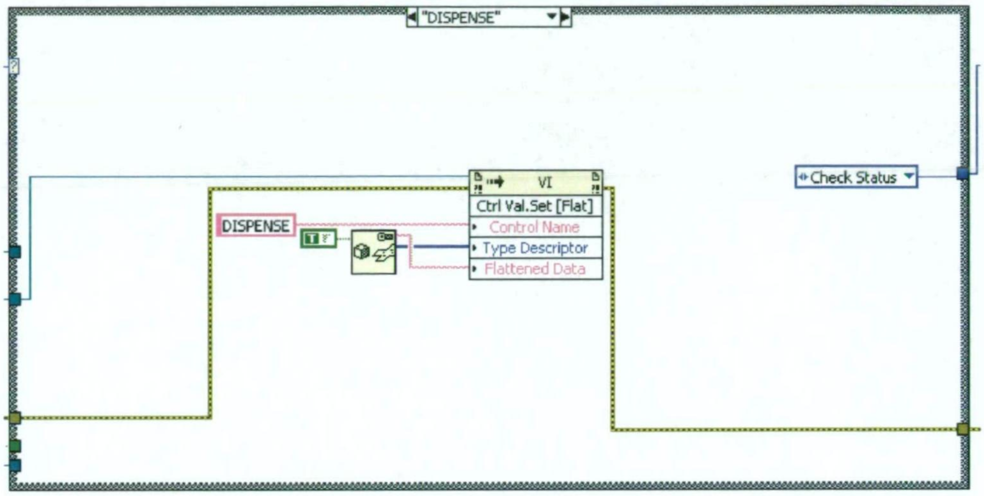


Figure 6-22 Dispense State

Query Tablets State

It is used for knowing the number of tablets in the dispenser. After the remote computer (client which is also the patient) receives this command, it requests the microcontroller in the dispenser to return the number of tablets in the dispenser and this number stored in the NoOfTab string is read after waiting for 3 seconds.

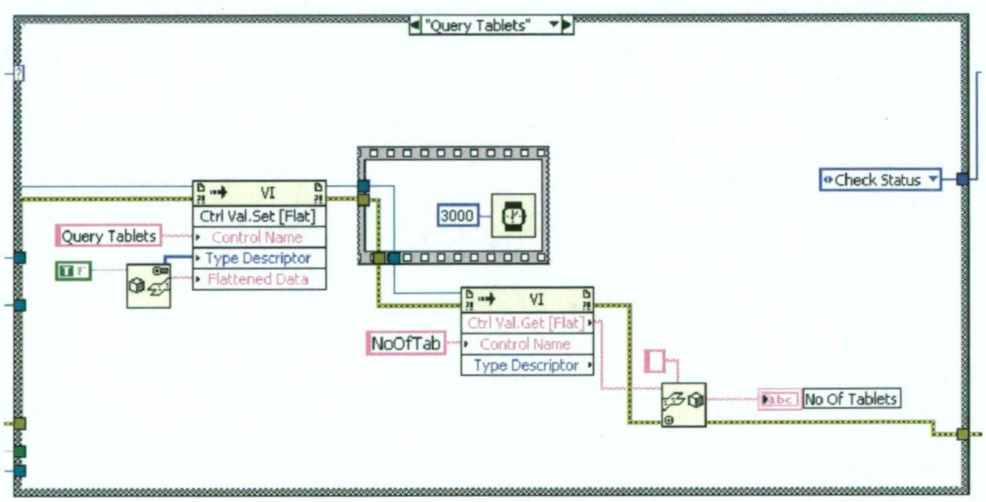


Figure 6-23 Query Tablets Dispense

Emergency Exit State:

Emergency Exit is needed in case of emergency exit. It halts the dispenser where it is.

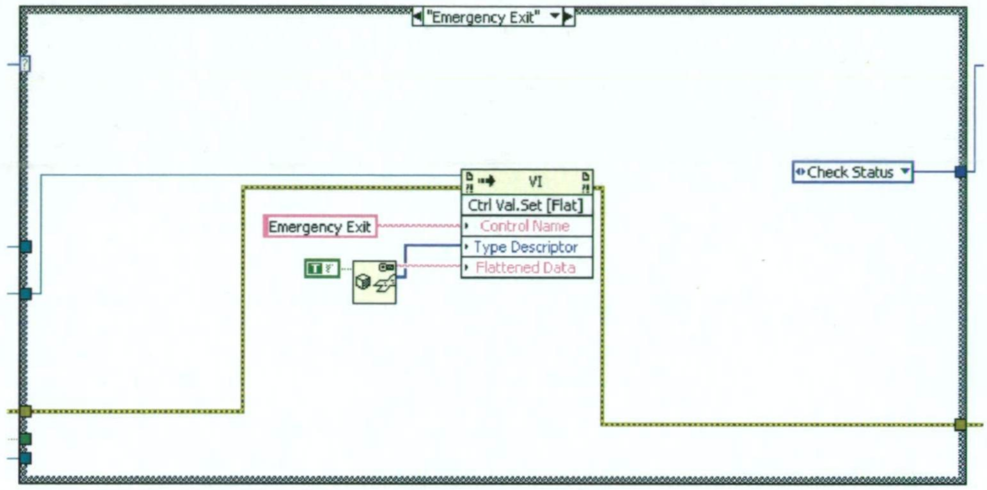


Figure 6-24 Emergency Exit State

Exit State:

This is to stop the dispenser and the remote program. It invokes the stop button to true (which is for stopping).

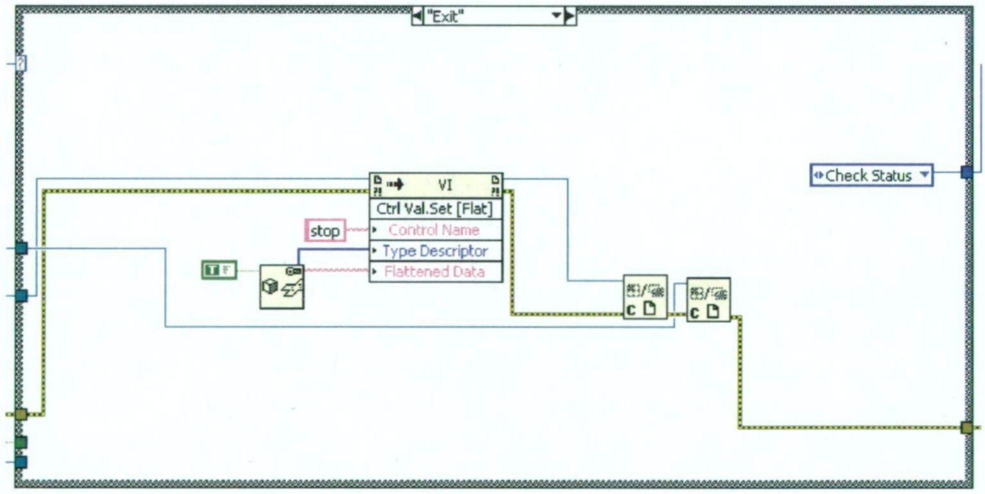


Figure 6-25 Exit State

Description of the program

The state diagram starts from Init (Initialization). The state initializes the variables including resetting indicators. Check Status is the intermediate state where the program stays waiting for a command or instruction from the user. The transition from one state to another is determined by the user command in this project. The states are from Dispense, Query, Emergency Exit or Error state. When the user (Server or the clinician) completes dispensing, s/he has to press exit to stop the program.

6.7 Refill dispenser

The medication dispenser has to be refilled before dispensing. This section describes the microcontroller program developed to perform the refilling and the corresponding VI for the loader (the pharmacist or the clinician) to interact with the dispenser.

Figure 6-26 shows the user interface for refilling. The detailed steps followed to refill the dispenser are described in the Appendix III. The loader (the clinician) has to click REFILL on the user interface to start refilling process (Figure 6-27). The ring box can be changed to input the number of tablets loaded (shown as three in Figure 6-26). This has to be done manually. Clicking complete, the VI sends the number of tablets the loader entered in the interface to the microcontroller (Figure 6-28) and the procedure is completed. The microcontroller reads the number and writes it in the EEPROM.

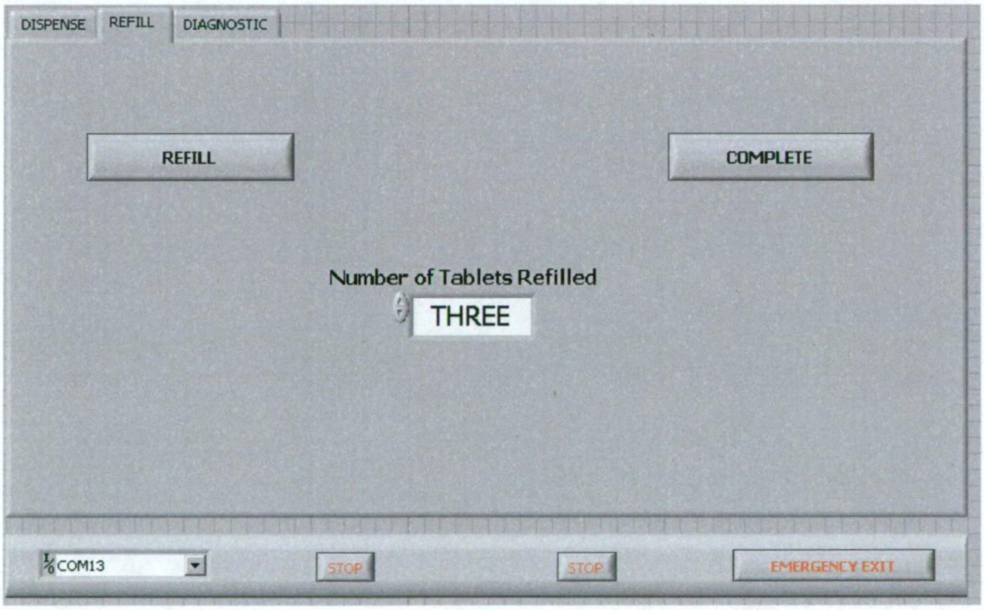


Figure 6-26 Refill Dispenser Front Panel

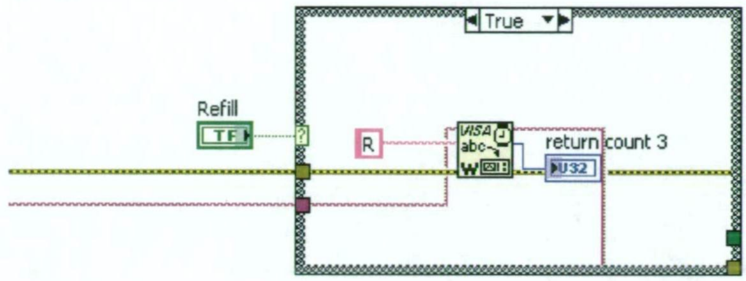


Figure 6-27 Block diagram for refilling

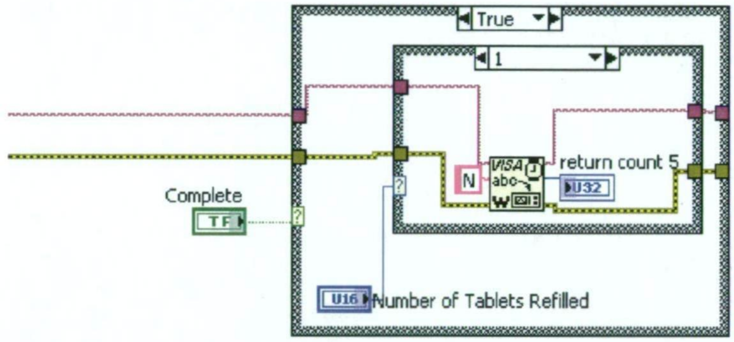


Figure 6-28 Block diagram for number of tablets to refill

Figure 6-29 shows the block diagram on how the microcontroller does the refilling. The subroutine `Refill_Dispenser` is called from the main loop when it gets instruction from the computer to start refilling (Figure 6-7). `Refill_Dispenser` calls the `Dispenser_Ready` function which extends the medication tube out of the metallic cover so that the clinician (the loader) can refill the tube with the desired number of tablets. The flowchart of the `Dispenser_Ready` subroutine is given in Figure 6-30. `Dispenser_Ready` pushes the tube out until it reaches the refilling position. Subroutine `Refill_Dispenser` also writes the number of tablets refilled as given by the user into the EEPROM memory. This number is required in the dispensing process.

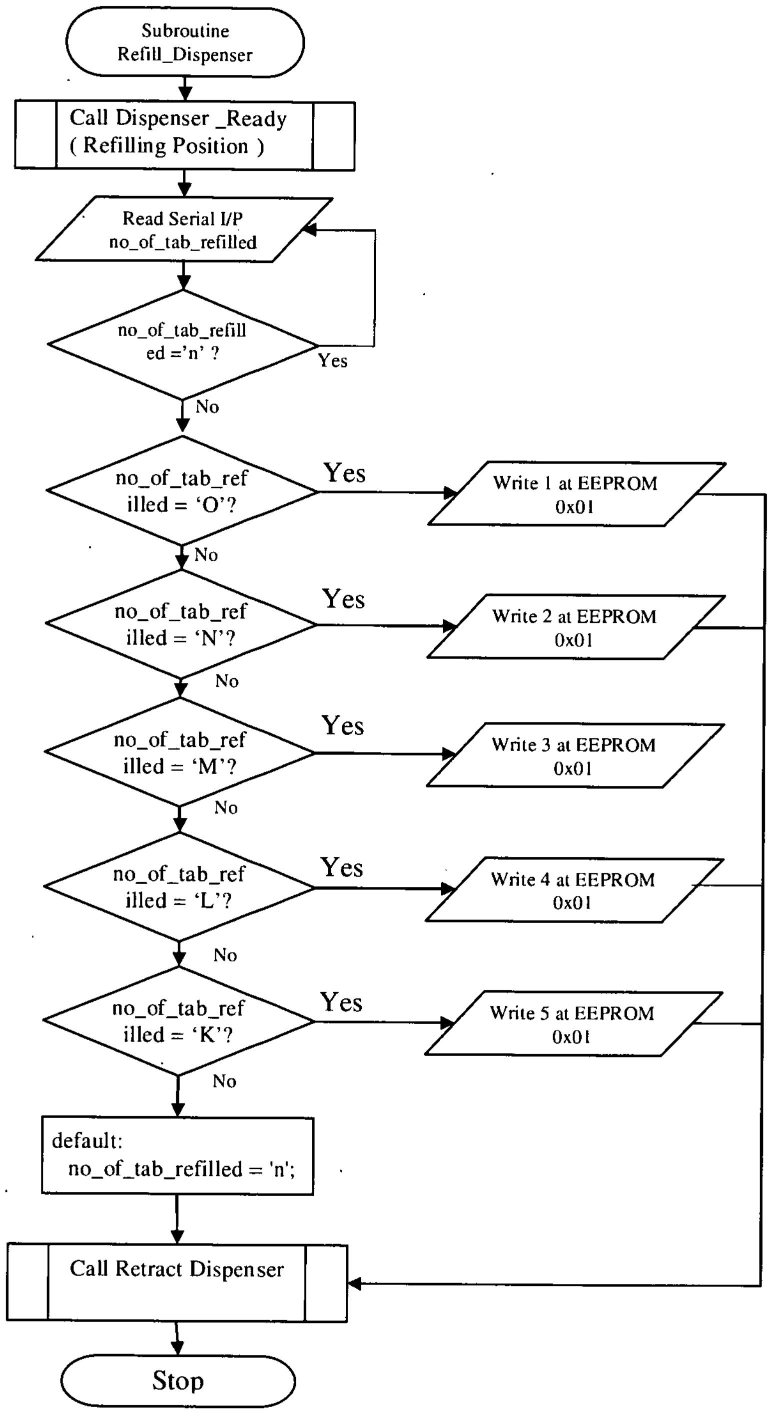


Figure 6-29 Flowchart to Refill Dispenser

6.7.1 Set dispenser in Ready Position to Refill

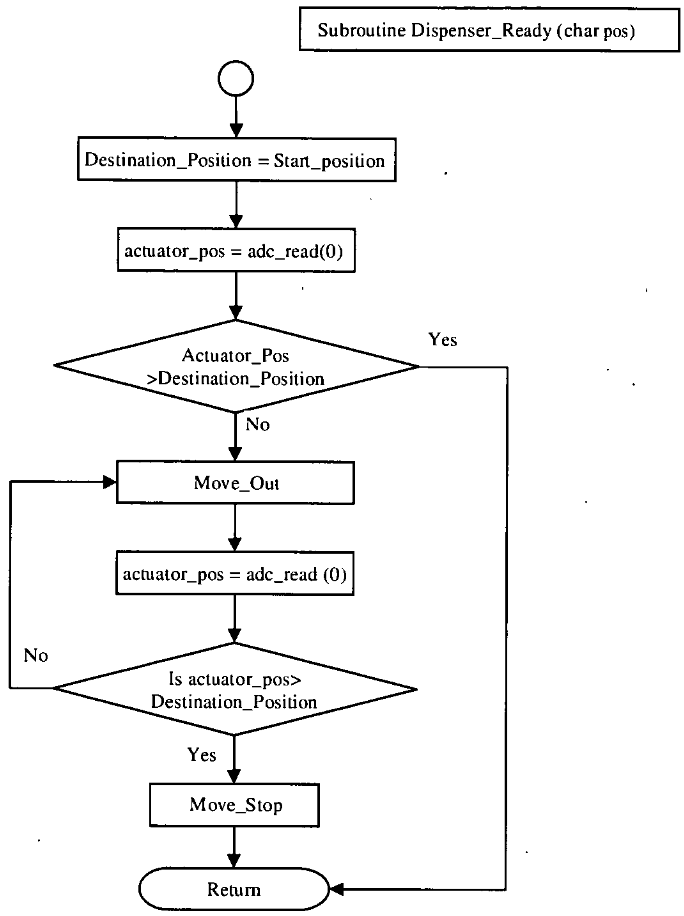


Figure 6-30 Subroutine Dispenser_Ready

If the network between the patients and the clinician is disrupted during the dosing period, the dosing would continue if the physician has authorized the dosing. If the dispenser looses power during the dosing, the dispenser would stop at then position. When re-powered, the dispenser would retract back and the whole process has to be repeated again.

7 Evaluation

7.1 Introduction

This chapter explains the evaluation of the system. The chapter starts with a literature review of evaluation in telemedicine projects. Then the aims of the evaluation for the project are listed and the methodologies used are explained. Initial experiments using the system with dummy patients and dummy tablets are then presented, followed by a trial with two narcotic rehabilitation patients.

Evaluation is an essential issue in telemedicine research and implementation[101]. Evaluation implies a description or assessment with a view to answering a question or a set of questions with the ultimate goal being decision making regarding safety, practicality and about utility[102]. Evaluation of telemedicine can be done on a continuing, expansive, appropriate and comprehensive basis[103] with focus on safety, efficacy and effectiveness. Economic feasibility and implications are also factors that may be taken into account. Some of the evaluation techniques and parameters as found in the literature are presented below.

Evaluation strategies could be both short and in-depth [104]. Verification of the technical parameters and validation is the short method. In-depth evaluation is divided into four stages. The first stage is evaluating quality and performance of both the system's hardware and software followed by a feasibility study performed in co-operation with the users and the telecommunication networks as the second stage. The third stage deals with the effects of the telemedical service. The final stage is the analysis of data emerging from phase three for a cost benefit analysis. There are two research questions for telemedicine evaluation according to Dhillon et al.[105]. The first is related to the biomedical and clinical field and include clinical effectiveness, efficacy and safety come are included in it. The second question is research regarding health services including access, quality, and cost of care, for which the measures are utilization, referral, convenience, opportunity cost, etc.

Evaluation of any telemedicine system may be complex and multidimensional and includes evaluation of system implementation, effectiveness and cost-effectiveness making evaluation of telemedicine a complex task[106]. So the best approach is to have a structured approach to the problem which assists to narrow down the perspective of analysis and be objective. Generally telemedicine first has to be evaluated to be safe, next that it is practical and finally that it is worthwhile. The first focus is on the system, then on the service and finally on the health care that is provided[102]. Zahlmann [104] mentions evaluation as a process based on prospectively planned separate steps as the fundamental principle. Each step should focus on a defined aim so as the results give a clear picture of whether the evaluation criteria are achieved or not. Zahlmann [104] suggests to approach evaluation with a predefined standard and cautions that failure to do so results in inconclusive results.

Hicks et al. [103] identified three specific dimensions that need to be considered in an evaluation: (1) level of analysis, (2) focus of analysis, and (3) activities of analysis. The three dimensions of analysis for evaluation of a telemedicine system are shown in Figure 7-1. The first dimension which is the level of analysis has three broad levels–individual, community, and societal[107]. The second dimension is concerned about the focus of the analysis. When health care is discussed, there are generally one or more of three major themes being addressed: cost, quality, and/or access. Acceptability is another theme important to the current work. The third dimension involves the activities of analysis. Once the technology and equipment are in place, telecommunication activities can take place for a variety of reasons—clinical reasons in controlled environment, educational, or administrative.

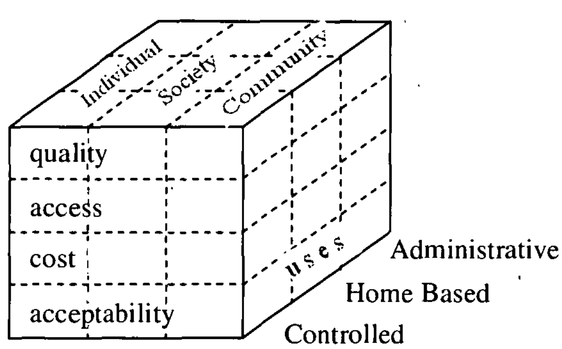


Figure 7-1 Three dimensions of Evaluation

Subjective evaluation is often the preferred method to measure effectiveness[108] and has been implemented in the project. The objective of subjective evaluation is to evaluate the user's perspective of the telecare services and the effect of the services on patients' lives[109]. In a clinical setting, this evaluation attempts to determine what occurs in the prevention, diagnosis, treatment, or eradication of a particular disease or illness with the application of a particular medication, procedure, device, or behaviour modification strategy. Economic evaluations add the determination of the resources that would have to be expended to implement the intervention.

The quality of the system has to be assessed from multiple considerations[110]. The number of questions that can be asked to evaluate the use and performance of telemedicine systems is virtually unlimited. However, given the scope of the project, the limited time and number of cases, evaluation for the project can be done on safety and efficacy from the user's perspective. The evaluation will therefore focus on the technical feasibility, personal benefit and socio-economic advantage of the remotely monitored narcotic dispenser system developed by the UTAS biomedical team. Technical parameters such as the resolution and quality of video frame preferred by the user will be determined by subjective feedback. Bandwidth required for the experiments and bandwidth available for different communication medium will also be explored.

Interestingly even using the best technology does not guarantee that the technology is acceptable by the ones who is actually are to use it - the doctor and the patients. Four groups of factors which possibly influence the acceptance and the use of the technology are mentioned by Mezni et al.[111], the four groups being perceptions of the user, individual factors, managerial factors and technical factors (Figure 7-2). It further explains that the perceived ease of use, the usefulness, the expected performance and user's effort to be the concepts behind perceptions of the user for the acceptance of the system. The technical quality of information and compatibility are also important if the user is to accept the system. Similarly, physician's attitude has a significant positive effect on the patient's intention to use the technology[112].

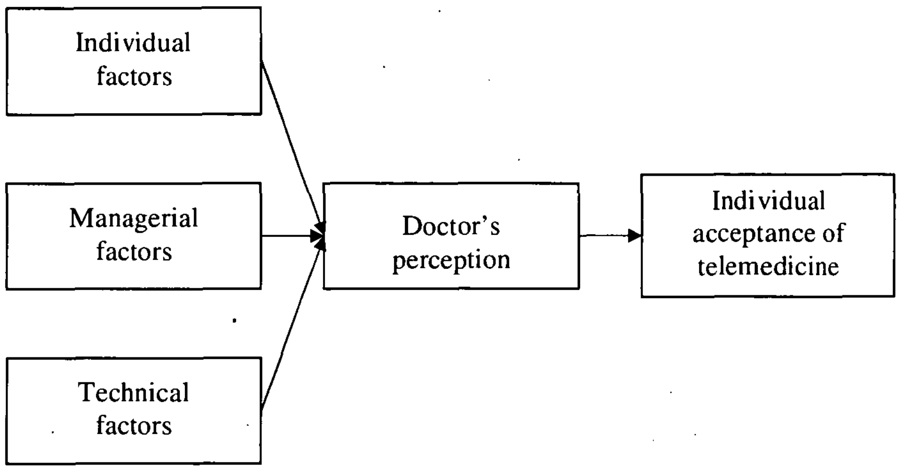


Figure 7-2 Factors accepting user acceptance of telemedicine [111]

Given the scope and time-scale of the project, it is only reasonable to consider performing a primary level of evaluation comprising quality, access, cost and acceptability. A much bigger project would be required to measure the effectiveness at the society level. The general approach taken will, therefore, be to show that there is no significant difference between the conventional medicine and telemedicine approach on patient outcome so that there is no negative effect from the use of telemedicine. There are also potential benefits in terms of quality of care, cost-effectiveness or improved accessibility.

7.2 Evaluation trials

Two groups of patients were used in the evaluation – dummy and real patients. Dummy patients were volunteers who had accepted to participate in the experiments. Even though not the intended targets of peoples, the feedback was useful for continuous improvement and development of project. The main aim of the evaluation is to find if tele-dosing is accepted by patients and whether the system developed in the project is suitable for tele-dosing. Other aims of the evaluation are to find technical parameters - best resolution for video for the purpose, maximum frame rate from webcam and highest compression level without affecting perception of quality. Feedback from end users was used to improve the software. Using these values, remote dispensing tests were performed. The users were asked to fill in a feedback form. This feedback was used for subjective evaluation. The evaluation aims can be broadly divided into two categories: determination of technical parameters and capacity (such as the best video frame rate, resolution and compression) and subjective evaluation of the program when used in remote dispensing. These are outlined in more detail below. The trials with the real patients were done to measure how useable the system it. The numbers of dummy patients were ten. The test lasted in an average of 15 minutes. The procedure required to undertaken for trials is included in the Appendix.

7.3 Evaluation of technical parameters

7.3.1 Aim

Determination of technical parameters: video frame resolution and compression level.

1. Best video resolution for video communication: There are five options of video resolutions that are available for the Logitech webcam - 160x120, 176x144, 320x240, 352x288 and software enhanced 640x480. Which is the best resolution as determined by subjective feedback from dummy patients?
2. Best compression level: A higher compression reduces bandwidth but also reduces quality. What is the minimum compression level for satisfactory video conferencing?

7.3.2 Methodology

Ten dummy patients volunteer for the test. All the subjects were male. The subjects were engineering student. The subjects were explained the purpose of the test and were asked to rate the questions based on the adequacy for the purpose.

1. Determination of technical parameters: video frame resolution and compression level.
    a. Best video resolution for video communication: Dummy patients were asked to give points in Likert Scale from 1 to 5 for each resolution, 1 being the poor resolution and 5 being the best. The resolutions were presented in a sequential order from worst to best. The resolution that was selected from the feedback was then used in the trials with real patients.

b. Best compression level: LabVIEW can compress video frame in JPEG format in different quality level. 750 is default. A lower compression factor results in higher video frame quality. The minimum is 0 which is the worst quality and maximum is 1000 which is the least compressed quality. The dummy patients were asked to rank the quality to be satisfactory or not starting from compression level of 50 with increasing steps of 50.

7.3.3 Result

Best video resolution:

The survey gave following results for the five video resolutions (Figure 7-3).

The 352x288 resolution got the highest score in the Likert score of 4.5. Even though 640x 480 has a higher resolution, users did not find it comfortable in the use of video for conversation. Hence 352x288 resolution was chosen as the resolution for experiments with real patients. Detailed statistical analysis of the best resolution is out of the scope for the current work.

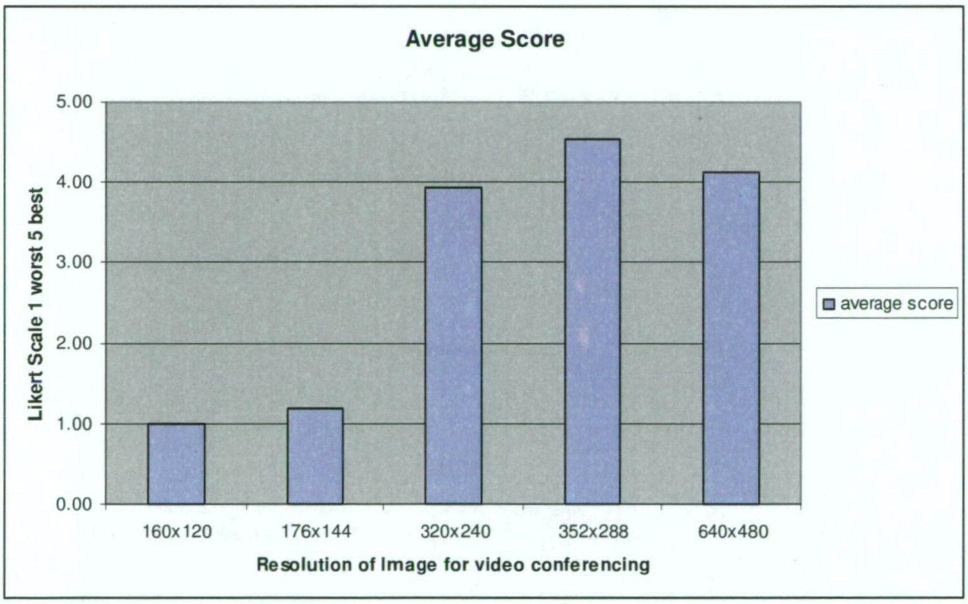


Figure 7-3 User feedback on preferred resolution of frame for video communication

Best compression level

LabVIEW can compress video frame in JPEG format in different quality level. 750 is default. A lower compression factor results in higher video frame quality. The minimum is 0 which is the worst quality and maximum is 1000 which is the best. They were shown pictures with quality level starting from 150 in increasing steps of 50 to 300. The results are shown in Figure 7-4.

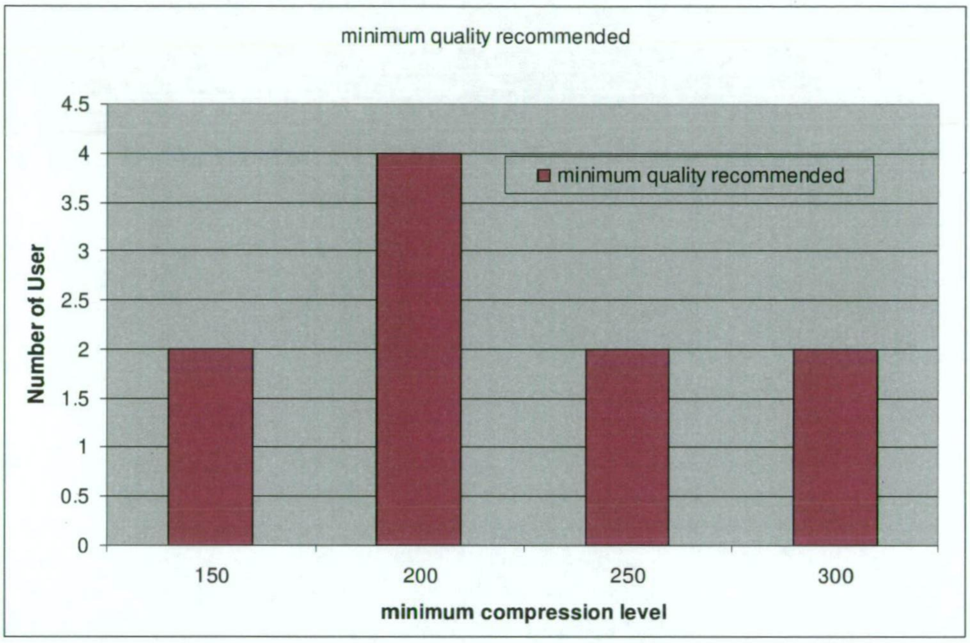


Figure 7-4 Minimum quality recommended out of four compression level chosen

The mean value for compression was found to be 220. 200, 250 and 300 were used in further investigation of image sizes and frame rates at different compression levels.

7.4 Evaluation of capacity of hardware and software

7.4.1 Aim

There were two aims of this experiment:

a. Best Frame Rate from webcam: A frame rate of 15 or more is considered as sufficient for a video conferencing. What is the maximum frame rate that can be obtained from the webcam after compression and decompression of video frames?

b. Video conferencing experiment bandwidth consumed: The ultimate aim is to use the internet as the communication medium. Generally wireless has lesser bandwidth than cabled internet. What bandwidth is consumed by the system and what available internet mediums have the required bandwidth?

7.4.2 Methodology

a. Best Frame Rate from webcam: Custom program inbuilt in the software was used to find out the frame rates at which frame can be capture from webcam at different software delays including compressing and decompressing. Frame rate as low as one frame per 2-3 seconds have been used in telemedicine experiment[113]. Fame rate of 0.5–5 fps is normal in wireless system[114]. Video frame rate of 25 fps gives the perception of natural motion. However, compression and decompression of the video frames drops the frame rate to 7.5, 10 or 15 fps[11].

b. Video conferencing experiment bandwidth consumed: Bandwidth required for the project was calculated by analysing the data obtained from BandWidth meter software.

7.4.3 Result

Best Frame Rate from webcam

According to the specification of the webcam, it can capture frames at 30 fps. However, during software development it was found that using higher frame rate caused program to slow down and the frames were not smooth. So different frame rates in which the images were captured from the webcam were found out by experiments along with the standard deviation of the measured fps.

Fps doesn't vary much with the resolution of video frame (Figure 7-5). The maximum frame rate possible is 27 frames per second at the program delay of 25 ms (at 25 ms of delay between two frames, the fps is 40). Another interesting point to note is standard deviation of fps is higher when delay is low (Figure 7-6 and **Figure 7-7**). *Standard deviation was used as a criterion to find out the best delay to be used for a smooth image capture.* Delay of 40 ms or higher were chosen to be suitable as they has lesser standard delay in frame rate. Since 20 fps is sufficient for video conferencing, 45 ms software was selected.

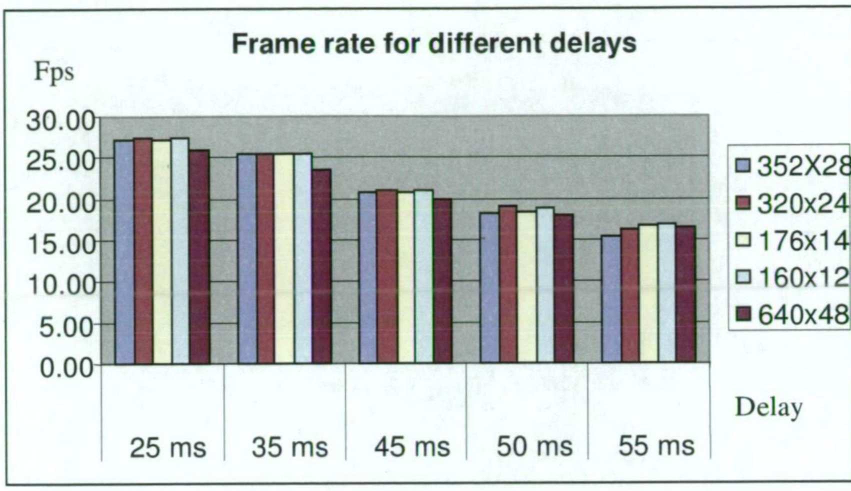


Figure 7-5 Frame rate for different delays

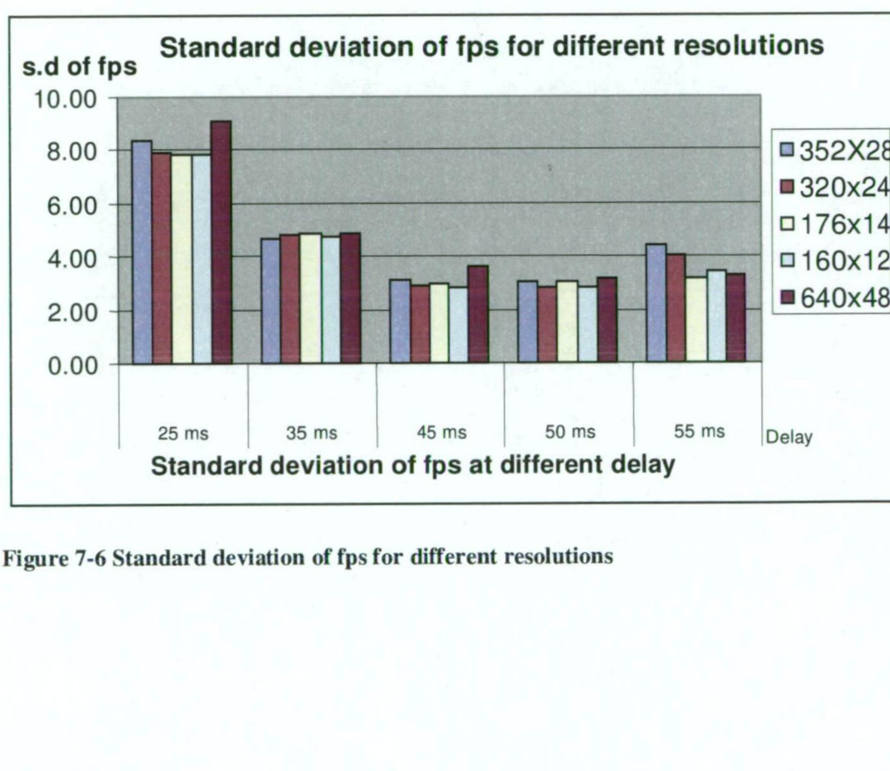


Figure 7-6 Standard deviation of fps for different resolutions

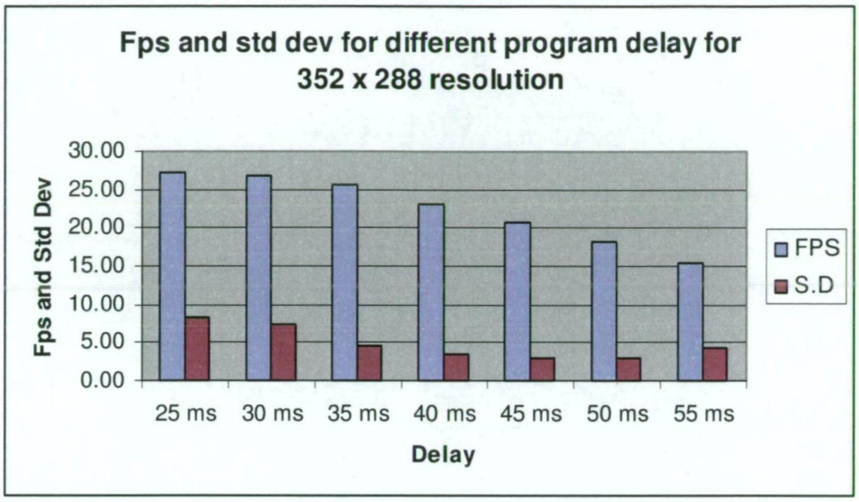


Figure 7-7 Fps and std dev for different program delays for 352 x 288 resolution

Video conferencing experiment bandwidth consumed:

Experiments were done to find out bandwidth consumed with three different compression levels. Few users found video quality with quality of 150 satisfactory so that was used as the minimum quality. The average frame size with 150, 250 and 350 compression level was found to be 4.3 KB, 5.5 KB and 7.0 KB respectively.

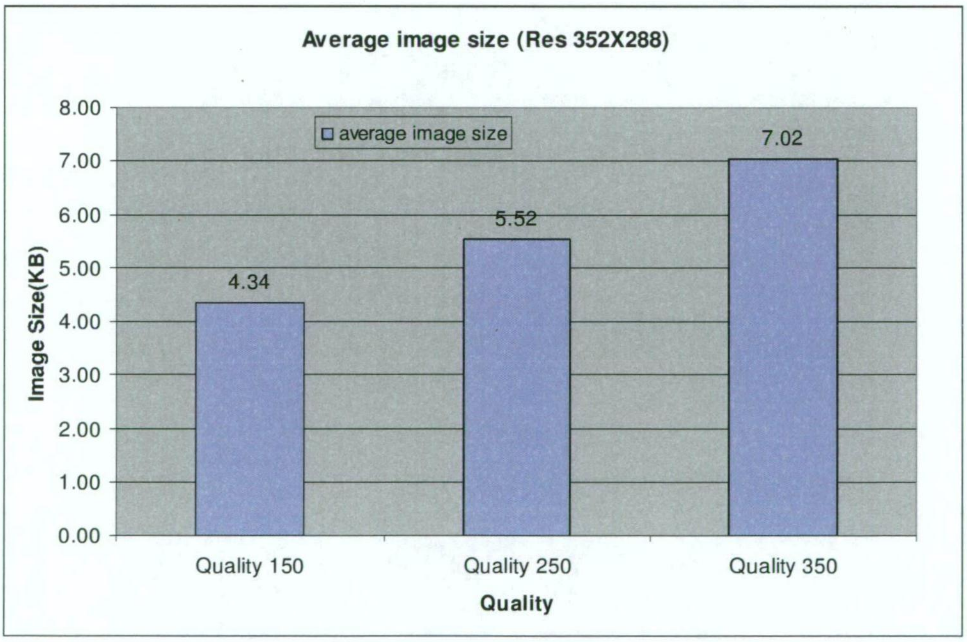


Figure 7-8 Average video frame size for video for different compression levels

Similarly in video conferencing experiment for the same three compression levels of 150, 250 and 350, the upload bandwidth was 86 KBps, 97 KBps and 113 KBps and upload speed was 99 KBps, 122 KBps and 151 KBps respectively (**Figure 7-9**). The result is also shown graphically in **Figure 7-9**. The frame size is important to calculate the amount of bandwidth required.

The above two results are not required for the thesis but is given as to provide some idea on how much bandwidth is required if it is used in transmission medium like wireless (3G).

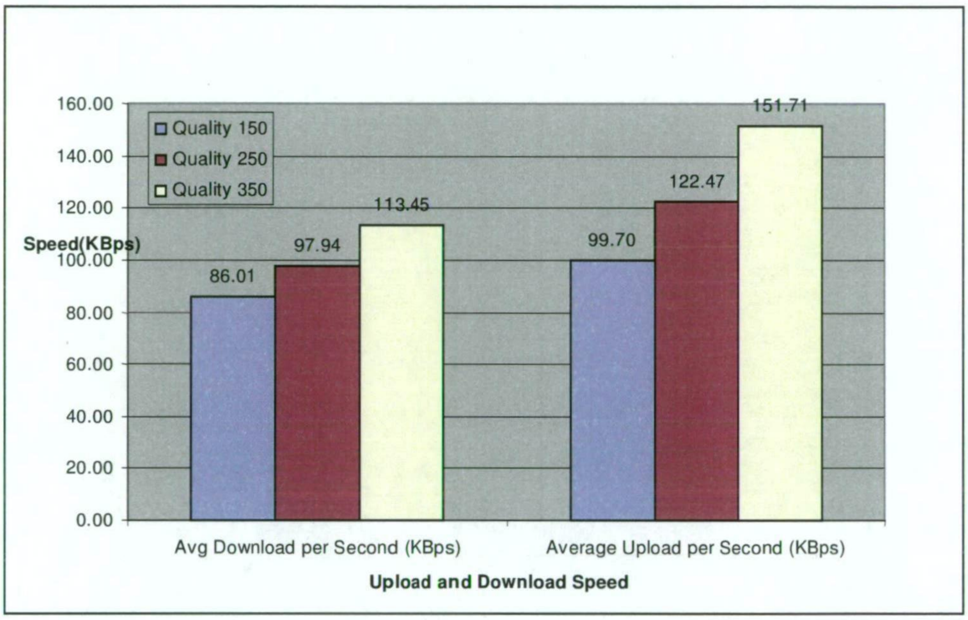


Figure 7-9 Average download and upload speed for different quality

7.5 Evaluation of tele-dosing and video conferencing

7.5.1 Aims

There are three main questions in tele-dosing and video conferencing experiments.

a. Video conferencing experiment: Video conferencing is an essential part of the project for remote dispensing, visual assessment for the doctor and communication between the two parties. The aim of the evaluation was to answer following questions:

   - Is the video quality suitable for the purpose based on frame rate and resolution used?

- Is the audio clear?
- Is Audio-Video quality adequate?

b. Tele-dosing:

- Is the system reliable?
- The question is regarding ergonomics – is the user able to use software without much help?
- Is the system easy to learn?
- Is the system useable and effective?
- Can the system dispense plastic tablets to dummy patients and ultimately the Buprenorphine tablets to real patients sublingually?

c. Cost willing to pay: The cost that the user is willing to pay for the service is important. What is the price that the patient is happy to pay for the use of technology in receiving medication remotely?

7.5.2 Methodology

A questionnaire was compiled to measure the usability of the system. The questionnaire was composed of 22 different questions using a five-point Likert scale. It was designed to measure the general satisfaction with carrying and using the system. Each subject was given a set of questionnaires (**Post-Dose Assessment Form – Patients**) to fill out after the experiment. The contents of the evaluation form were consistent with the objective of the analysis. The evaluation phase was used in continually improving the program to make it efficient and better. The goal of evaluating telemedicine system is to ensure that the healthcare data provided by telemedicine are useful as those provided by conventional means. The data is obtained by the experiments carried out under controlled environment.

1. **Video Conferencing experiment:**

   The video Conferencing experiment involves user's perception of the audio-video communication trials. Feedbacks from the users were used in quality assessment and improvements in the software. It can be further divided into following subsections.

a. **Evaluating Video Quality:** Following questions were asked with the users to determine the quality of video.

- The video frame is a suitable size for comfortable viewing.
- The color and clarity of the video frame is good.
- The video frame rate is reasonable.
- The video quality taking above three in aspect is good.

b. **Evaluating Audio Clarity:** Echo and loss of data and delay are major problems with audio clarity. The focus has been on minimizing the bandwidth consumed by audio without compromising quality. Since real time audio communication is integral part of the system, the following questions were used to assess this area. Less delay and loss are required for good communication.

- I can hear the doctor clearly through the headphone.
- There is no echo in the sound?
- The audio quality taking above two aspects in good.

c. **Evaluating Audio-Video Quality.** Since audio data and video data are being sent separately, synchronization between them is important. It is also dependant on the bandwidth supported by the medium. Synchronization is very important because it can be used to know the mental condition of the patient or in other words, loss of synchronization may result in misinterpretation of the incorrect mental condition.

- To what extent were the lips synchronized with audio when somebody spoke?
- Please rate audio-visual quality taking all aspects into account.

d. **Teledosing:**

Teledosing was conducted with both dummy and real patients. The Teledosing system was used in these trials. Teledosing with dummy patients involved using dummy tablets which were dispensed into a container instead of the mouth. Apart from this the dosing was done as described below for the real patients.

Teledosing with real patients involved trialling the system in a controlled environment within a narcotic rehabilitation centre. The trial was done with two patients. (More patients are scheduled for trials in the future, but there was no opportunity for inclusion on these in the trial covered by this thesis.) Ethics approval was obtained from the Tasmanian Human Research Ethics Committee for this trial. Patients were dosed individually. During dosing, the patient sat with an observer in one room with the dispenser loaded with their Buprenorphine dose. The system's webcam was mounted on the dispenser for initially viewing the patient and also the tablets inside the patient's mouth following ejection from the dispenser. The dispenser and webcam were connected to a PC that was networked through LAN to a second PC in another room. A dosing supervisor supervised the dosing session from this other room through the interface on the second PC. In this trial, the patients were dosed with their normal daily Buprenorphine tablet dose. The dose was taken sublingually, with the tablets dispensed directly under the tongue and left there until they were fully dissolved. The time taken to dissolve the tablets was around 5 minutes.

The teledosing questions were related with whether dispensing took place successfully or not and the sequence of dispensing (for example there should be a break between dispensing of two tablets). A number of criteria were included to evaluate teledosing. Since the patient would be reluctant to undergo the trials if they find that system is unreliable so reliability is a very important aspect. The user's perception of reliability is as important as the number of successful experiments. To measure reliability, patients (both dummy and real) were asked to respond to the statement

- The system is reliable.

The user should be allowed to concentrate on the task rather than how to do do the task when operating the system. The software is intended to be intuitive and provide information in a format which is easy to use[56]. To test whether this is the case, users were asked the questions:

- It is easy to setup the system.
- It is easy to learn and get familiar with the system.

Remote control of the narcotic dispenser is key function of the system. One assessment of it is the number of successful dispensing operations that took place. The users were therefore asked if the remote dispensing was completed successfully or not. The statement in the form is:

- The goal of remote dispensing has been achieved.

One of the goals is to evaluate the useability and clinical effectiveness of the system and hence measure healthcare effectiveness. In other words, the user perception or acceptance of the system. Technology acceptance means an individual's psychological state toward his or her voluntary use of a particular technology[112]. The ultimate evaluation should be determining if the system has helped decrease the fall out rate and rehabilitation success which would take time. But in this short term study the focus has been to determine patient satisfaction with the healthcare service of the tele-consultations and remote dosing and the technology acceptance by the targeted group through the questionnaire. The patients' feeling of comfort and confidentiality is therefore assessed as feedback for useability/effectiveness. The statements to get the feedback on this are:

- The communication with the doctor through the system is just like a normal conversation.
- The goal of remote dispensing has been achieved.

Patients were asked to compare conventional way and telemedicine dosing through the statement "Home dosing through this system is better than going to pharmacist". The remote end dosing supervisor's also asked the same question.

e. **Cost users are willing to pay for system:** Cost that patients are willing to pay is an important factor to be considered. If two ways of providing the same health care services are equally effective and available, the lower cost method is the preferable method. Cost-effectiveness evaluation has two components:

cost and effectiveness[106]. Two general questions were used to get some idea on the amount of money the users are willing to pay.

i. I am happy to pay $20/week for the service.

ii. I am happy to pay $40/week for the service.

Since initially there was no idea on the cost involved $20 and $40 was chosen as a rough figure to indicate some costs the users are willing to pay.

7.5.3 Results:

The results of the experiments done with dummy patients are shown in Table 7-1. The third and fourth columns show the mean of the user feedback and the standard deviation of the feedback. The last column shows the mean of feedback from the real patients.

Table 7-1 Questionnaires asked with dummy patients and the result (mean and standard deviation)

No	Question	Dummy Patients		Real Patients
		mean	std dev	mean
Q1	The image is a suitable size for comfortable viewing.	3.17	1.07	4
Q2	The color and clarity of the video frame is good.	3.83	0.69	4.5
Q3	The video frame frame rate is reasonable.	3.33	0.47	4
Q4	The video quality taking the above three in aspect is good.	3.83	0.37	4.5
Q5	I can hear the doctor clearly through the headphone.	4.00	1.00	5
Q6	There is no echo in the sound.	4.50	0.50	4.5
Q7	The audio quality considering above two aspects is good.	4.17	0.37	5
Q8	The lips were synchronized with audio when the person at the other end spoke?	4.17	0.37	3.5

Q9	The audio-visual quality is good for communicating with the doctor.	4.00	0.00	4.5
Q10	The system of remote dispensing should be portable.	4.00	0.82	4.5
Q11	The system is portable.	4.00	0.89	3
Q12	I would like this system in my home.	4.50	0.50	
Q13	The system is safe.	4.20	0.75	4.5
Q14	The doctor is skilful in supervising the system.	4.20	0.75	5
Q15	The system is reliable.	4.00	0.00	5
Q16	It is easy to setup the system.	4.33	0.47	3.5
Q17	It is easy to learn and get familiar with the system.	4.20	0.40	4.5
Q18	The goal of remote dispensing has been achieved.	4.20	0.40	5
Q19	Home dosing through this system is better than going to pharmacist.	4.50	0.50	5
Q20	I am happy to pay $20/week to have this type of dispensing system in my home instead of going to the pharmacy daily.	*	*	4
Q21	I am happy to pay $40/week to have this type of dispensing system in my home instead of going to pharmacy daily.	*	*	3
Q22	The communication with the doctor through the system is just like a normal conversation.	*	*	4
	mean	4.06	0.54	4.3

The user feedback was positive and optimistic. The feedback from dummy patients clearly indicated general satisfaction with the service. The positive results led to experimenting with real patients.

Results with Real Patients

A pictorial description of dosing of one real patient has been presented below. This user was dosed with only one Buprenorphine Tablet of 8 mg. Figure 7-10 shows the medication tube extending out for ready position. Figure 7-11 shows the medication being pushed by the linear actuator. The push button has to be pressed during process.

Figure 7-12 shows the tablet placed in the sublingual position. The pictures have been trimmed to focus only on the mouth to conceal the patient's identity.

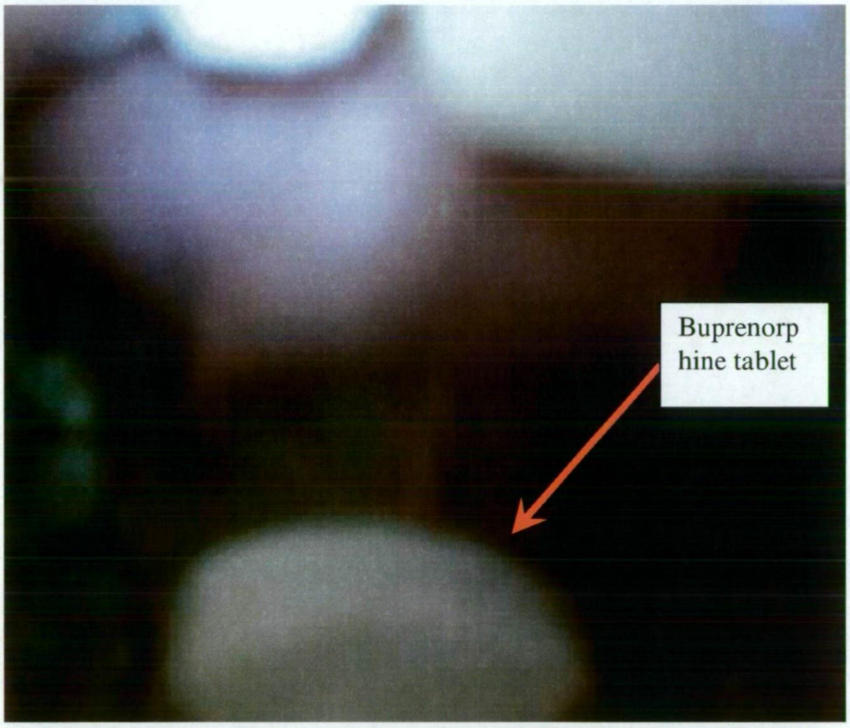


Figure 7-10 The medication tube extending out from the metallic case

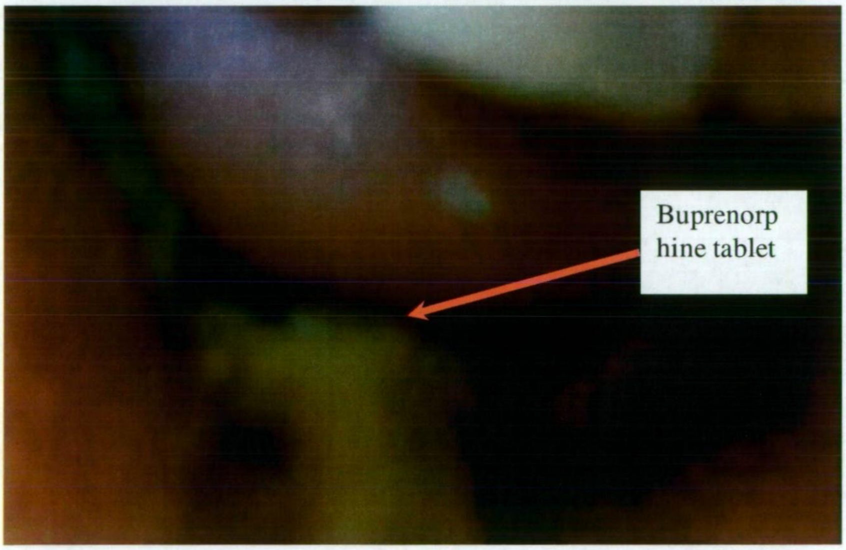


Figure 7-11 The linear actuator pushing the tablet out

Figure 7-12 After the dispensing of the tablet (the white oval)

The results with the two real patients are shown in Table 7-1 last column. Both the users agreed that they felt it comfortable to receive dose through the medication dispenser. Both the trials were successful. The first user had "strongly disagree" feedback which was for the question "The system is portable". The second user had low points for two questions – "The lips were synchronized with audio when the person at other end spoke" and "I am happy to pay $40/week to have this type of dispensing system in my home instead of going to pharmacy daily."

Contact with the General Practitioner or Pharmacist while getting dosed remotely was pointed out as an outstanding feature of the system. Freedom from travel for daily pharmacy attendance and associated risks - anonymity breach and association with known drug abusers was another outstanding feature mentioned in feedback. One of the positive outcome of the system as mentioned in the feedback was that this teledosing system would make dosing easier than attending the pharmacy yet would provide similar interaction with the pharmacist and, freedom to dose without being in the public eye without having to wait. The clinician feedback on the system was good in an average. The clinician is one of the supervisors of the project and he has been involved since the beginning. His comments were that he would like to see the system being implemented in real world and using multiple cameras so that he can assess the patient better. It would be one of the future works.

7.6 Conclusion

The system was successfully experimentally trialled to determine technical parameters and to assess its performance, usability and acceptance. It was particularly exciting to see the acceptance and positive reception from the real patients. Future work will be to trial the system with larger numbers of real patients, and in a take-home environment rather than in the controlled environment of the narcotic centre.

8 Conclusion and Future Work:

For this project, a tele-drug-rehabilitation system was designed, developed and implemented. Two important features of the system developed as part of the thesis were audio-video communication and tele-dosing. The medication dispenser was developed by Ho V[96]. The dosing supervisor at the server end remotely controlled the narcotic dispenser. The system was implemented over a LAN network. The entire project was developed in LabVIEW. The microcontroller used to control the dispenser was programmed using the C programming language and Microchip's PICC compiler. Software to refill the dispenser was developed. The VI Server feature of LabVIEW was used for remote control of the dispenser. Two application design patterns – independent parallel loop and state machine were used for the remote control of the dispenser. Use of state machine architecture gave the flexibility to easily make any changes to the control system, which was important since the medication dispenser was modified over the course of project. The system was evaluated in trials with "dummy" and "real" narcotic rehabilitation patients. The concepts behind the software are described in detail in the thesis using flowchart and codes.

The audio-video communication using webcams and headphones performed well. MJPEG format was used for video communication. WAV format which is the uncompressed format was used for audio. The bandwidth required for audio-video communication was 1200 Kbps. The remote control of the dispenser for medication dispensing was successful.

The project was tested with dummy patients in a lab environment. As the main objective of the thesis was designing, developing and implementing a trial system, the overall project was a success.

Currently the test bed of the project is LAN. In future, the project should be tested with the internet as the communication medium. When using the internet, a number of issues like duplicated frames, lost frames and jitter have to be dealt with. Future work can be use of compressed video codecs instead of MJPEG to save bandwidth. There is a facility for password protection in the project; however, no security protocol was considered in the project. Using a secure protocol instead of only TCP or UDP should be implemented in future development. The remote assessment technique is currently under development[2]. The technique should be included in the future. A number of other considerations should be making the system more user friendly. The system should also be tested outside LAN environment to test its effectiveness. The current system is not designed with adverse situations like power failure or network disconnection. It has to be considered in the future developments. There are also areas for improvement in user-friendliness. The system was developed in LabVIEW however other softwares like Java which is platform independent could be considered.

In conclusion, the project has developed and tested a tele-dosing system. Even if the small number of trials on real patients made it difficult to make any firm conclusions on the usefulness of the system, the initial feedbacks were positive. The successful trials show that tele-dosing is possible and can be a part of tele-drug-rehabilitation. The tele-dosing can not only be useful for drug-rehabilitation but other medical fields as well where direct supervision of dosing is important from both security, compliance and monitoring point of view.

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Appendix

I. Specification of PIC16F873

	Program Memory Type	Flash
	Program Memory (KB)	7
	CPU Speed (MIPS)	5
	RAM Bytes	192
	Data EEPROM (bytes)	128
	Digital Communication Peripherals	1-A/E/USART, 1-MSSP(SPI/I2C)
	Capture/Compare/PWM Peripherals	2 CCP
	Timers	2 x 8-bit, 1 x 16-bit
	ADC	5 ch, 10-bit
	Temperature Range (C)	-40 to 85
	Operating Voltage Range (V)	2 to 5.5
	Pin Count	28
	Working frequency	20 MHz

II. Post-Dose Assessment Form – Patients

SECTION A: In-mouth medication dosing device, multiple-choice questions

Answer each question by circling only one of the numbers.

The meaning of the numbers is as follows:
1 = Strongly disagree 2 = Disagree 3 = Neutral 4 = Agree 5 = Strongly agree

a) The dosing device is small.

1 2 3 4 5

b) The dosing device is portable.

1 2 3 4 5

c) The dosing device is easy to use.

1 2 3 4 5

d) The dosing tube felt comfortable in my mouth.

1 2 3 4 5

e) I felt relaxed when using the dosing device.

1 2 3 4 5

f) Home use of the dosing device would be OK for me.

1 2 3 4 5

g) The dosing device would help stop dose diversion and other wrong use of doses.

1 2 3 4 5

h) It would be good for this device to be used for all take-away doses given to me.

1 2 3 4 5

i) I felt comfortable using the dosing device.

1 2 3 4 5

j) It would be good for this device to be used for all take-away doses given to other people.

1 2 3 4 5

SECTION B: Open-ended questions

a) What do you think are the outstanding features of this tablet dispenser?

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b) What do you think needs improving or adding to the tablet dispenser?

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c) What features would you like to see removed from the tablet dispenser?

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SECTION C: Remote dispensing and video conferencing, multiple-choice questions

Answer each question by circling only one of the numbers.

The meaning of the numbers is as follows:
1 = Strongly disagree 2 = Disagree 3 = Neutral 4 = Agree 5 = Strongly agree

a) The video frame is a suitable size for comfortable viewing.

1 2 3 4 5

b) The colour and clarity of the video frame is good.

1 2 3 4 5

c) The video frame rate is reasonable.

1 2 3 4 5

d) The video quality taking the above three in aspect is good.

1 2 3 4 5

e) I can hear the doctor clearly through the headphone.

1 2 3 4 5

f) There is no echo in the sound.

1 2 3 4 5

g) The audio quality taking above two aspects is good.

1 2 3 4 5

h) The lips were synchronized with audio when the person at other end spoke?

1 2 3 4 5

i) The audio-visual quality is good for communicating with the doctor.

1 2 3 4 5

j) The system of remote dispensing should be portable.

1 2 3 4 5

k) Current system is portable.

1 2 3 4 5

l) I would like this system in my home.

1 2 3 4 5

m) The system is safe.

1 2 3 4 5

n) I am happy to pay $20/week for the service.

1 2 3 4 5

o) The doctor is skilful in supervising the system.

1 2 3 4 5

p) I am happy to pay $40/week for the service.

1 2 3 4 5

q) The system is reliable.

1 2 3 4 5

r) The communication with the doctor through the system is just like a normal conversation.

1 2 3 4 5

s) It is easy to setup the system.

1 2 3 4 5

t) It is easy to learn and get familiar with the system.

1 2 3 4 5

u) The goal of remote dispensing has been achieved.

1 2 3 4 5

v) Home dosing through this system is better than going to pharmacist.

1 2 3 4 5

III. Setting up the experiment

Two setup protocols need to be followed for the experiment: installation and clinical protocols. They are the steps that have to be followed so as to allow obtaining an evaluation of the system. The technical reliability of the set-up is as important since technical problem makes it difficult for people to co-operate and make them feel vulnerable[109].

A. Installation Protocol:

1) LabVIEW run time environment and LabVIEW vision run time environment should be present in both client and server computer.
2) Both sides should have executable of the LabVIEW program.

B. Clinical Protocol:

Following steps are to setup the Client computer.

Server:

a. Connect the webcam.
b. Connect the headphone and microphone.
c. Click Start (It should be on).
d. Note the IP of the computer.
e. Run the server (Ctrl+R).
f. Start consultation.
g. Remote assessment.
h. Remote dispensing.
i. Record the success of dispensing and any technical problem.
j. Click stop to stop the server.

Client:

a. Connect the webcam.
b. Connect the headphone or microphone (depending on whether you want to use laptop's microphone) Note: don't use speakers because it returns as echo.

c. Connect the medical device and note the com port.

d. Set the com port in the user interface.

e. Write the Server's IP address on the Server address space.

f. Click Ctrl+R to run the program.

g. To stop the program click Stop.

h. After the remote computer authorizes the use of dispenser, and the dispenser protrudes out.

i. Hold the red button on the dispenser until the first tablets comes out. Then leave the button for a while. Repeat the process until all tablets are dispensed.

j. The inner tube goes inside automatically after all tablets are dispensed.

k. The patient fills the final questionnaires for evaluation.

C. Refill the dispenser

The steps below show how to refill the dispenser. The intermediate steps that take place in the background are also mentioned.

a. Connect the dispenser to Computer via Serial Port. Currently USB to Serial is being used.

b. Note the COM port which is 13 for this instance.

c. Click *Refill* button in the LabVIEW program (Figure 6-26).

d. LabVIEW sends command to microcontroller to start refilling steps.

e. The medication tube of the dispenser protrudes out completely.

f. Load dispenser with the tablets.

g. Enter the number of tablets refilled. There is a ring input box (Figure 6-26) to input the number.

h. Click *Complete.*

i. The VI sends the number to microcontroller which then writes this number in the EEPROM.

j. Finally, the user has to press the push button on the dispenser.

The dispenser tube retracts back which is the end of dispensing process.

IV. Sub VIs for Video Sending

Brief descriptions of the built-in sub VIs used in video sending are given. They are referred back in the detailed description of the VI.

IMAQ USB Enumerate cameras:

`IMAQ USB Enumerate cameras` is used to list all connected cameras to the system that can be initialized. The first data in the array is passed on to next step.

Figure 0-1 IMAQ USB Enumerate cameras

IMAQ USB Init:

The name of the USB camera is the input for the `IMAQ USB Init` VI. This VI initiates an IMAQ USB session. The video mode parameter allows specification of a particular acquisition mode of the camera. In the webcam five different modes are possible (Table 3-1).

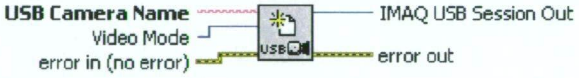

Figure 0-2 IMAQ USB Init

IMAQ Create:

A temporary memory location or an image reference is created using `IMAQ Create`. This image reference is then supplied as input to all subsequent (downstream) functions.

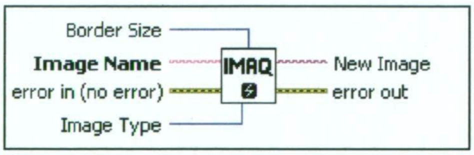

Figure 0-3 IMAQ Create

IMAQ USB Grab Setup:

`IMAQ USB Grab Setup` VI starts a continuous acquisition. Once the acquisition has started, `IMAQ USB Grab Acquire` is called to copy images from the continuous acquisition. Only one camera can acquire at one time.

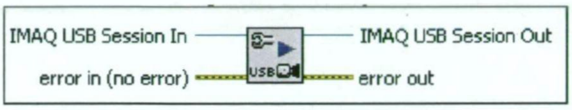

Figure 0-4 IMAQ USB Grab Setup

IMAQ USB Grab Acquire:

`IMAQ USB Grab Acquire` acquires an image frame during a continuous acquisition.

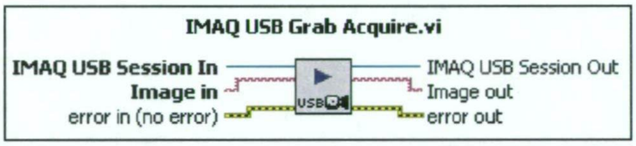

Figure 0-5 IMAQ USB Grab Acquire

IMAQ Flatten Image to String:

`IMAQ Flatten Image to String` returns the string representation of an image using the provided options. The options are quality (1000 to 0, 1000 being the best), compression (none, JPEG or packed binary) and type of flatten (image, image and vision info and reference to the image).

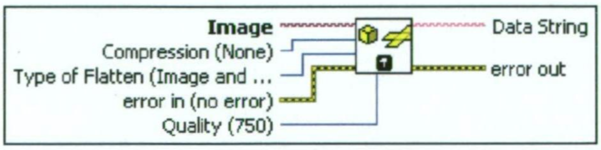

Figure 0-6 IMAQ Flatten Image to String

TCP Listen:

`TCP Listen` creates a listener and waits for an accepted TCP network connection at the specified port.

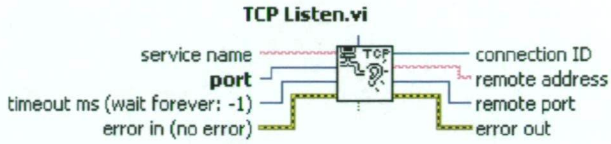

Figure 0-7 TCP Listen

TCP Open Connection:

`TCP Open Connection` establishes a connection with the TCP Listen at the address and the remote port supplied to it.

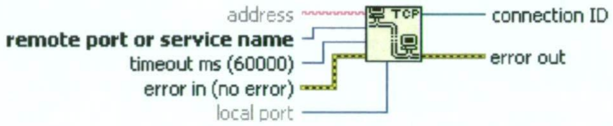

Figure 0-8 TCP Open Connection

TCP Write:

`TCP Write` writes data to a TCP network connection.

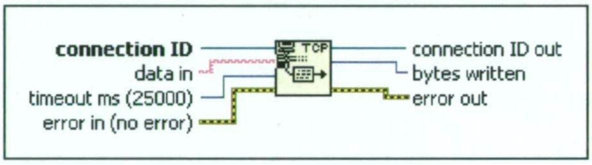

Figure 0-9 TCP Write

TCP Close Connection:

`TCP Close Connection` closes a TCP network connection.

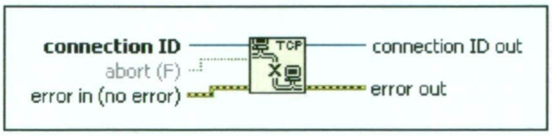

Figure 0-10 TCP Close Connection

IMAQ Dispose:

`IMAQ Dispose` destroys an image and frees the space it occupied in memory. It VI is called when the image is no longer needed in the application.

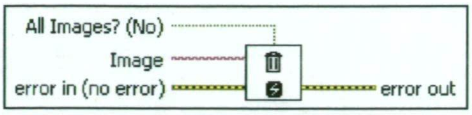

Figure 0-11 IMAQ Dispose

IMAQ USB Close:

`IMAQ USB Close` closes the session to the USB camera. `IMAQ USB Init` is used to open it.

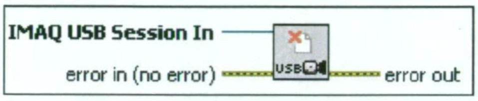

Figure 0-12 IMAQ USB Close

Type Cast:

Type cast is used to cast any data to the data type, type, by flattening it and unflattening it using the new data type. If the function must reinterpret data instead of transforming it, LabVIEW uses a temporary buffer. Type cast is used to convert numeric data into string because TCP only accepts strings as the data format.

V. Sub VIs for Video Sending

At the receiving end, the following sub VIs are additionally used:

TCP Read:

`TCP Read` reads a number of bytes as specified from a TCP network connection, returning the results in data out (Figure 0-13). It can work in four modes - Standard (0), Buffered (1), CRLF (2) and Immediate (3). Standard mode is used in the program such that `TCP Read` waits until all bytes specified in **bytes to read** arrive or until **timeout ms** runs out. It returns the number of bytes read so far. If fewer bytes than the number of bytes requested arrive, it returns the partial number of bytes and reports a timeout error.

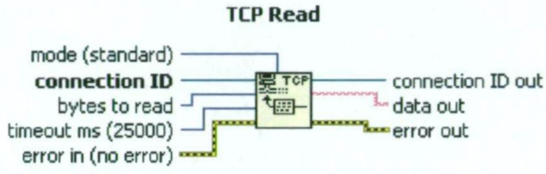

Figure 0-13 TCP Read

Unflatten from String:

The image frame is in string format. To convert it back to image format, the `Unflatten from String` is used (Figure 0-14). The flattened string is the input to binary string and the type should be an image reference. The value output gives the image reference after unflattening from string.

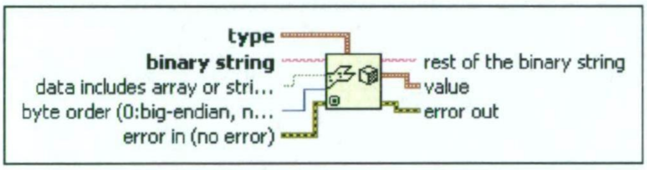

Figure 0-14 Unflatten from String

Type Cast:

`Type Cast` is used to convert the string into number. It is used to convert the number representation of length of data in string format back to number.

Figure 0-15 Type cast for image length data