Post Operative Monitoring of Kidney Transplanted Patients Using Wireless Sensor Networks

Alice Abraham, Srinath K. S. Guru. Prasad B. S. Sumanth, and Narendra Kumar G.

Abstract—**Although kidney transplantation is a successful treatment for end stage kidney disease, complications can occur that include bleeding, vascular thrombosis, renal artery stenosis, ureteral stenosis, lymhocele, fever, rejection, etc. Post transplant monitoring and prompt medical attention and early treatment will be decisive in a successful transplant and recovery and this monitoring can be improved by great bounds using wireless sensor networks. Nephrologists need real time data to monitor various parameters of the patients for periodic medical requirements. Some medications may be prescribed for only 7 to 14 days, such as antibiotics. Others, like your anti-rejection medications are usually prescribed for lifetime. In case the data received has variations in the threshold value of the parameters, report is sent to doctor's (nephrologist) PDA and nurse in charge for necessary action. In immaculate medical assistance, consultants can rely on this extremely high potential Intelligent Sensor Networks that provides near accurate pathological and physical parameters which are obtained from six wearable sensors namely creatinine, temperature, respiration, ECG, blood pressure, and heart rate that are placed on the patient's body which sends the sensed data through wireless network using E-AODV protocol to a Personal Data Transceiver(PDT) and the nephrologist's PDA.**

Index Terms—**Access points, E-AODV, MANETS, PDT, wireless sensor network.**

I. Introduction

According to WHO in 2005 there were as many as 66,000 kidney transplants throughout the world. In US alone about ten percent of the entire population i.e., 20 million people are suffering from chronic kidney diseases, among them most of them need transplant of kidney with more than 69 thousand deaths in the world. In the present day due to heavy stress in day to day life many suffer from kidney diseases caused by decreased extracellular volume, renal losses use of diuretics, decreased cardiac output , toxins build up due to medications like anti-inflammatory and iodine-containing drugs, antimicrobials, Myoglobin rhabdomyolisis, significant breakdown of body muscle etc.. These lead to an exponential increase in cases of kidney transplant, hence care must be taken for routine health checkups- this is where wireless real time monitoring is helpful.

There are two stages in real time wireless monitoring of transplanted kidney. The first stage is to monitor a patient while in ICU i.e., just after patient has had a kidney transplant. The second stage, after patient is discharged from ICU or hospital during the period there is a possibility that kidneys are rejected as foreign body.

The proposed system makes use of six different sensors with wireless transmission ability to monitor vital parameters of the body to achieve real time wireless monitoring of transplanted kidneys. The patient is provided with a PDT which acts as a transceiver to transmit the received signals from the sensors to a computer which maintains the database of that patient whenever a variation is detected. Patient care software with algorithms to continuously monitor patient's vital signs in the database and alert the nephrologist of critical changes

Transmission from the handheld device (Personal Data Transceiver) to the database occurs periodically, if no variation in the vital points from the normal behavior is detected for the allocated period. In case a variation from normal behavior is detected those instant values are transmitted to the database via PDT and the details of the corresponding patient are sent to the concerned nephrologists when patient care software detects a change.

II. Related Work

Recent study reports initial results of the development of the System for integrated adherence monitoring (SIAM), a non adherence risk assessment system for tacrolimus and sirolimus for the pediatric kidney transplant population. Forty-eight youths between 10 and 25 yr of age diagnosed with chronic kidney disease or a kidney transplant used an electronic pill bottle to dispense their medication for at least 30 days or until their next clinic appointment. Youth completed a self-report adherence measure, and standard deviations were calculated for the last four medication serum trough levels obtained for each patient. Estimation models were developed for each medication (i.e., SIAMTACRO and SIAMSIRO) to assign weights to these clinically available adherence measures (self report and trough levels) for the calculation of a non-adherence risk composite score. SIAMTACRO models included both self report and tacrolimus trough levels and significantly predicted EM. For sirolimus, the model predictive of adherence as measured by EM consisted of the standard deviation of sirolimus trough levels only (SIAMSIRO). Non-adherence risk can be effectively assessed using clinically available assessment tools [1].

III. Proposed Monitoring System Design

A. Related Sensors

According to WHO standards to detect any problem in the working of the transplanted kidney, monitoring of six vital

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The authors are with University Visvesvayraya College of Engineering, Bangalore, India (email: alice.abraham@gmail.com,: alice.abraham@gmail.com).

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points namely: Creatinine, Temperature, Respiration, ECG, Blood Pressure and Heart Rate is performed.

B. Creatinine Sensor

A non-invasive continuous Glomerular Filtration Rate (GFR) estimation system is described as one embodiment including a Foley catheter, a continuous urine creatinine sensor, a urine output monitor and a creatinine clearance computational circuit are interfaced measures creatinine clearance which is a function of time, serum creatinine, urine output, and urine creatinine. The timed creatinine clearance estimation equation is represented as

$$r_{cl} = (U_{cr} U_{vol})(P_{cr} . T_{\min})$$

where U_{Cr} is urine creatinine in mg/dL,
U_{vol} is urine volume in mL,
P_{Cr} is plasma (serum) creatinine in mL
T_{min} is time in minutes.

A Foley catheter may be used to withdraw urine from the bladder. The urine may be delivered to a creatinine clearance measurement system which includes a urine output monitor that measures total urine output providing the U_{vol} value.. The urine output monitor provides the U_{vol} value to a creatinine clearance computational circuit. Attached to the catheter is a flow-through creatinine sensor for continuous monitoring of urine creatinine providing the U_{Cr} value of the creatinine clearance equation presented above to the creatinine clearance computational circuit.

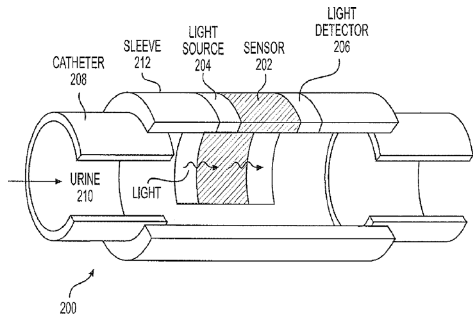


Fig. 1. Creatinine sensor.

With all of the parameters for the calculation of creatinine clearance now provided, creatinine clearance can be computed. An exemplary creatinine clearance computational circuit receives a urine creatinine signal from the continuous creatinine sensor and a total urine output signal from the urine output monitor. The creatinine clearance computational circuit may include a user interface for enabling a user to establish a start time so that total elapsed time can be determined, and for enabling the user to input a serum creatinine value obtained from a laboratory. Since all of the parameters except serum creatinine are received on a continuous basis, the creatinine clearance computational circuit is able to compute as estimate for creatinine clearance (and therefore GFR) on a continuous basis [4].

C. Temperature Sensor

Thermistor has been chosen as the temperature sensor. General Electric's MA300 10k thermistor is a non-linear thermistor with tolerance of 0.2C. It can measure temperatures ranging from 0C to 50C and has a fast response time and low power dissipation, which makes it ideal for such medical application. The sensor is small and can be placed anywhere on the body. However, its placement is chosen to be in the ear. Temperature measurements taken in the ear are accurate and relate closely to true core body temperature.

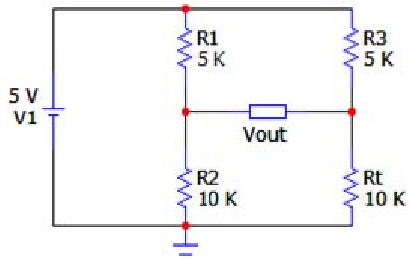


Fig. 2. Temperature sensor.

Normal temperature ranges in the ear vary from 35.8C to 38C. Change in temperature causes the thermistor's resistance to change accordingly. The relationship between thermistor's resistance and temperature is non-linear. Four resistors are used in this configuration and one of them being the thermistor. As the thermistor's resistance changes due to change in temperature the output voltage also changes. The advantage of using a Wheatstone bridge is that it accurately measures small changes in resistances and produces a voltage output which is sent through an ADC into the microcontroller. Inside the microcontroller there is a lookup table that has temperature values corresponding to voltage values [5].

D. Respiration Sensor

Conductive rubber belt with electrical resistance changed by lengthening was incorporated within the patient's pants, which operate as a waist band transducer. The resistance changes induced by the abdominal dimension variation during breathing were converted into a voltage signal by a bridge circuit which are digitized followed by wireless transmission [6].

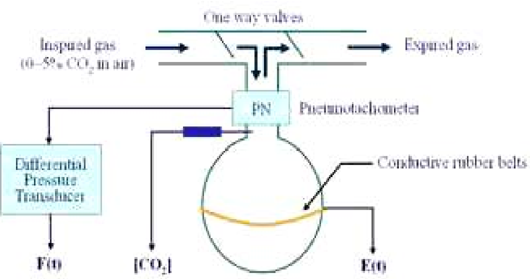


Fig. 3. Respiration sensor.

E. ECG Sensor

Wearable electrocardiograph (ECG) monitoring system use a wearable and ultra-low power ireless sensor node called Eco which does not require direct contact to the skin, and has comparable performance to gold standard ECG electrodes. The wireless interface will add minimal size and weight to the system while providing reliable, untethered operation. The system has a separate data-sampling module, which contains a microcontroller unit (MCU) and ADCs. All signals from ECG sensors are first sampled and buffered in the module and data are fed to Eco via SPI and transmitted through wireless channel to the base station. This architecture uses two MCUs to distribute workload.

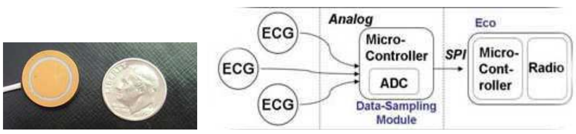


Fig. 4. ECG sensor.

The MCU in the data-sampling module is dedicated to sampling signals. The other MCU in the Eco node handle wireless data transmission. The two-MCU architecture achieves very accurate data sampling (low jitter) as well as high communication throughput and low latency. [7].

F. Blood Pressure Sensor

A monolithic integrated tactile sensor array is used to perform non-invasive blood pressure monitoring of a patient. The advantage of this device compared to a hand cuff based approach is the capability of recording System for integrated adherence monitoring: Real-time non-adherence risk assessment in pediatric kidney transplantation continuous blood pressure data. The capacitive, membrane-based sensor device is fabricated in an industrial CMOS-technology combined with post-CMOS micromachining. The capacitance change is detected by a sigma modulator which is operated at a sampling rate of 128kS/s and achieves a resolution of 12 bit with an external decimation filter and an OSR of 128 [8].

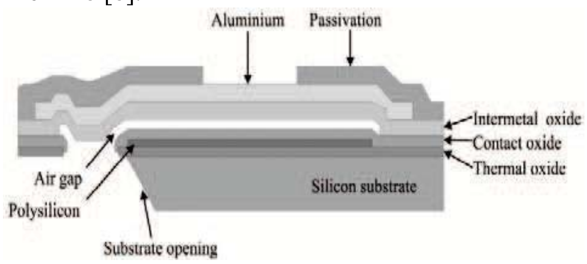


Fig. 5. Blood pressure sensor.

G. Heart Rate Sensor

A miniaturized telemetric photoplethysmograph ring sensor for long-term, continuous monitoring is used. The ring sensor is attached to a finger base for monitoring beat-to-beat pulsation. The ring encapsulates photoplethysmographic, pulse oximetry combined with wireless communication. The ring sensor consists of optoelectronic components, a CPU, an RF transmitter, a battery, and a ring chassis. The optoelectronic components i.e., micro photodiodes and LEDs, detect the blood volume waveforms and oxygen saturation level in the patient's digital artery. The CPU controls the LED lighting sequence as well as the data acquisition and transmission process. These signals are locally processed by the on-board CPU and transmitted via RF transmitter for diagnosis of the patient's heart rate conditions. Two major design issues i.e., to minimize motion artifact and to minimize the consumption of battery power are overcome by an efficient double ring. Total power consumption is analyzed in relation to the characteristics of the individual components, sampling rate, and CPU clock speed and optimal operating conditions are obtained for minimizing the power budget [10].

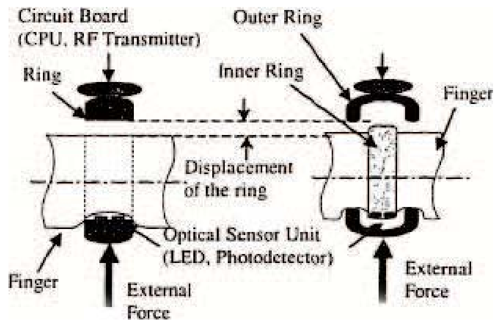


Fig. 6. Heart rate and pulse sensor.

H. PDT Design

For the proposed system, Personal Data Transceiver needs to receive data from the six sensors and transmit the received data to the database. After the PDT receives the data from the six sensors using wireless network, processing of the received data will be done and decision making with the help of an algorithm where the obtained values are compared with the standard values is achieved. Finally transmission of conditions of the patient using wireless sensor network using E-AODV protocol to the database is achieved if there is any deviation in the sensed values from standard values. When no deviation is registered for a certain period, the sensed data will be sent to database for database update. PDT is also provided with a GPS system by which the whereabouts of the patient can be tracked.

I. Communication System

For the proposed system Enhanced AODV protocol is implemented (E-AODV). The Enhanced-AODV ensures optimized communication between the nodes(PDTs) and the database. During the first stage of monitoring the paper mainly concentrates on communication between sensors and PDT on the patient and to the base station Fig.9. There will be a node on each patient which sends data and forwards packet by the created communication channel for data transfer. Each mobile node operates as a specialized router and routes are on-demand with little or no reliance on periodic advertisements. The source node initiates path discovery by broadcasting a route request (RREQ) packet to its neighbors. The pair source address and broadcast ID uniquely identifies a RREQ. Broadcast ID is incremented whenever the source issues a new RREQ. Each neighbor satisfies the RREQ by sending a route reply (RREP) back to the source or re-broadcasts the RREQ to its own neighbors after increasing the hop count. As the RREQ travels from a source to various destinations, it automatically sets up the reverse path from all nodes back to the source. The Distance Vector Table contains the information about the direction and distance of the neighboring nodes. The Path memory table deals with the number of nodes per sector and help in creating the path for the packet. The Data received by the Base Station is sent to the hospital database.

During the second stage the paper concentrates on communication between PDT and database. A web portal to connect with the patient record database and make the real-time patient information accessible to nephrologists is used. Each nephrologist and in charge nurse is provided with a PDA using which they can access the readings of patient's physical parameters as and when required.

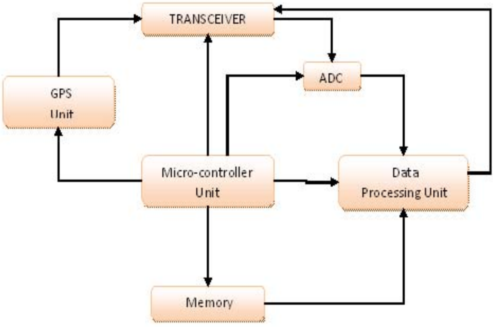


Fig. 7. Architecture of personal data transceiver.

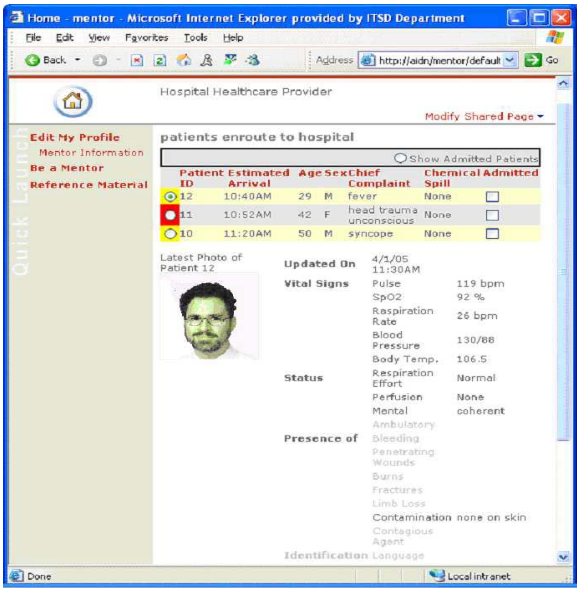


Fig. 8. Web portal to access the database.

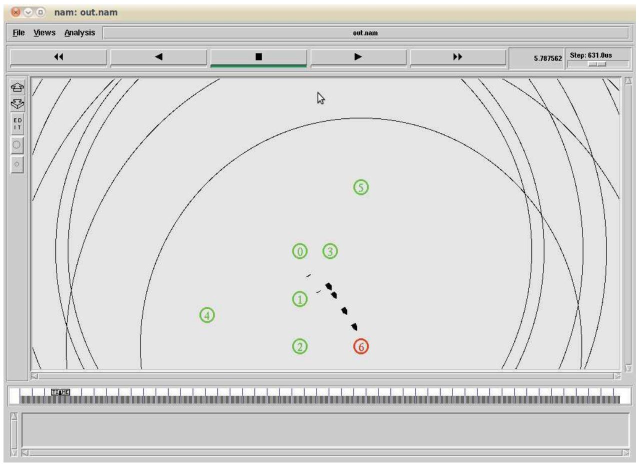
If any variation is detected in the database patient care software which automatically analyzes the patient's vital signs, alerts the nephrologist PDA of abnormal changes. When the authority wants to access the data, they send a request using their PDA containing the patient IP address. Depending on this request, the server sends the reading to the PDA of the authority. The actual biometric parameters will be available on the PDA of the authority after this.

III. System Model

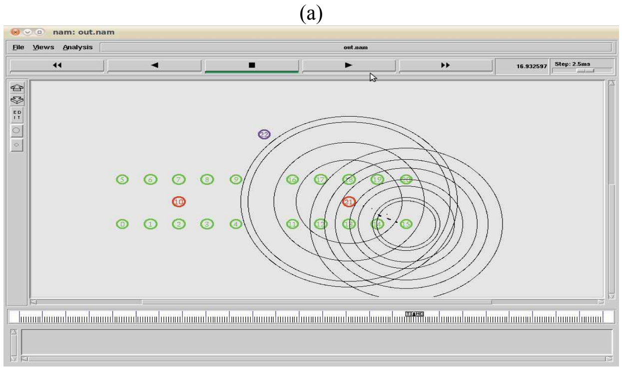
The proposed system is implemented using six sensors for vital biometric parameter measurement. Personal Digital Transceiver for receiving digital data from the sensors and forwarding it to base station is used. Base Station for forwarding of received data to the hospital's database and to the nephrologists' PDA is maintained. After measuring the vital points the transmission of the measured values from the sensors to the PDT is achieved. The data transmission occurs through wireless channel over E-AODV protocol. PDT is provided with an extra time slot in case nodal connectivity to other PDTs is required. By PDT's connectivity property, a fully robust network for the transmission of the vital point measurement values is achieved. The selection of PDT for hopping is determined by the location updates which are stored in the routing table.

During the first stage of monitoring adhoc network is used with E-AODV protocol to implement the wireless sensor network. During the second stage of monitoring adhoc network is used only for 1km range around the hospital as over one 1km range adhoc network will cause a considerable delay, in which case either internet or mobile communication network which has global coverage can be used to transfer data from patients PDT to web portal and to hospital database then onto doctor's PDA.

The received data in the database will be analyzed and compared with the standard threshold values. In case of any change the concerned doctor and the nurse station will be notified about the emergency. The Doctor will have to respond to this notification immediately irrespective of pre occupation. In case the doctor/consultant is not in the vicinity of the patient, an emergency call is generated to the Doctor's/consultant's cell phone from the Server. A notification is also sent to the prioritized doctor/consultant available in the hospital and the family members.



(a)



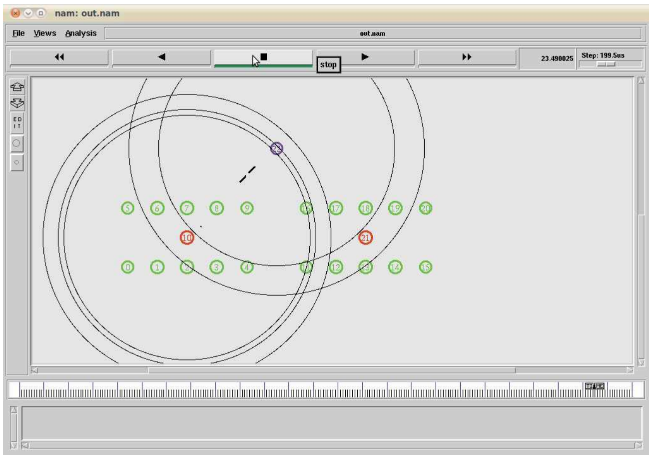
(b)

Fig. 9. (a) Simulation showing the data transfer from individual sensors to the PDT node.
(b) Simulation showing the data transfer from PDT

IV. Simulation And Results

Network Simulator-2 is used to simulate the communication network of the proposed system over Enhanced-AODV protocol with 2-D topology. Wireless channel proposed uses E-AODV protocol with a packet size of 10kB and an interval arrival time of 10 packets per second.

The data traffic generation is performed using File Transfer Protocol Model. The transmission of data from each node to the base Station is sent over a multiplexed wireless channel of 1ms duration per node. As wireless channel proposed use TCP transmission protocol any data loss that occurs will be rerequested and obtained by the respective node. Two-Ray ground propagation model is used in the simulation with omnidirectional antennas.



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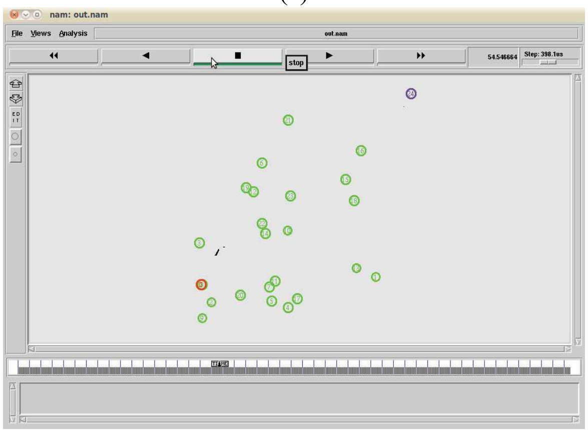

(b)

Fig. 10. (a) Simulation showing the data transfer from access point to the main base station.
(b) Simulation showing the data transfer after discharge of patient's PDT (while he/she is moving) to the main base station.

V. Conclusion and Future Work

Network using AODV protocol for inpatient and Outpatient monitoring has been simulated in Network Simulator-2 and found to be working successfully. The monitoring of the kidney transplanted patients can be achieved economically and effectively by the proposed wireless monitoring model.

The proposed Real-time Post Operative monitoring of kidney transplanted patients collects various biometric parameters of the patient and sends it over a wireless network. This system ensures proper monitoring of the patients and helps in case of emergencies as well which uses enhanced-AODV protocol.

The future work will be on the implementation of a system on monitoring other medical parameters of the human body which can be applied in all the hospitals and on all the patients.

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Alice Abraham is a graduate in Electrical Engineering and a post graduate in Power Electroniis , both from University Visvesvayraya College of Engineering, Bangalore, India. Currently a research scholar in Bangalore University in the Department of Electronics & Communication, she is actively involved in research in the areas energy efficiency and applications of Wireless sensor networks under the guidance of Professor Narendra Kumar G.

Ashutosh Tripathy, Jeson Kamalnath, Naresh T., Samarth Bharani are undergraduate students in the Department of Electronics & Communication, University Visvesvaraya College of Engineering, Bangalroe, involved in research in the area of wireless sensor networks under the guidance of Professor. Narendra Kumar G.

Narendra Kumar G. was born in Bangalore on 5th February, 1959. Obtained Masters Degree in Electrical Communication Engineering, (Computer Science & Communication) from Indian Institute of Science, Bangalore, Karnataka, India in 1987. Was awarded PhD in Electrical Engineering(Computer Network) from Bangalore University, Bangalore, Karnataka, India in 2006. Currently Professor in the Department of Electronics & Communication Engineering, University Visvesvaraya College of Engineering., Bangalore University, Bangalore, held the positions of Associate Professor, Lecturer and Director of Students Welfare. Research interests include Mobile Communication, Wireless Communication, E-Commerce, Robotics and Computer Networks.