Wireless Sensor Network Applications in Urban Telehealth

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Abstract

Advances in wireless sensor network management have potential applications in urban telehealth. Telehealth is the delivery of health related services and information via telecommunications technologies. Previous efforts on telemedicine management have focused on medical care for rural populations, however urban communities will benefit significantly from advances in wireless network design and management. Within the domain of occupational and physical therapy, known as telerehabilitation, expected active benefits to urban communities include greater adherence to rehabilitation protocol due to ease of use and removal of the travel requirement for multiple weekly trips to clinical site and clinical appointments. Additionally, passive benefits are envisioned to include monitoring of the environment, such as balconies, interior and hallway spaces for detection of road and urban pollutants, including cigarette, exhaust, and cleaning products. The integration of active and passive sensing would provide a more complete picture of the therapy client’s living environment and the therapy practice within that environment. This information can be provided by the proposed wireless sensor network application.

1. Introduction

Significant advances in remote monitoring for health care and rehabilitation have been made in rural communities through the use of telehealth systems [1], specifically though service provisioning. As is the convention in the health care field, this paper considers both telemedicine and telerehabilitation to be included in the term telehealth. Often, these systems provide video-conferencing to rural patients, which permit patients to receive the attention of occupational therapists and medical specialists which might not otherwise be available. These services, referred to as ‘telerehabilitation’ are offered to individuals with a wide range of disabilities and a variety of prognosis. The internet access which provides this service is either a dial-up or dedicated connection, with standard video-conferencing software. Examples of such use include low-speed Internet connections for initial patient interviews with medical professionals and observation of daily living tasks [2].

With the advances in wireless sensor networks, a larger community of healthcare clients can be served with a greater range of services. Additional benefits can be provided to the community, which include greater adherence to therapy protocols, reduction in travel, and enhance therapist-client understanding. Several of these additional services will be examined with emphasis on the urban telehealthcare environment.

2. Telemedicine

Rural health care has been the focus of telemedicine research. The work conducted by Intel in opening rural telemedicine clinics in both India and China has been well received. In India, rural patients can now visit a local telemedicine clinic which is staffed by only one nurse, but provides a telemedicine connection to an eye specialist [3]. Comparable solutions are expected to be implemented in China. This access significantly reduces travel times for patients, as well as providing medical care to individuals who might not have otherwise received it.

A complementary area of research is in the field of telerehabilitation. Telemedicine refers to “the use of medical information exchanged from one site to another via electronic communications for the health and education of the patient or health care provider and for the purpose of improving patient care” [4]. In contrast, telerehabilitation refers to “the provision of rehabilitation services, such as occupational therapy, physical therapy, and speech-language therapy using telehealth technology” [1].

While access to rehabilitation professionals, particularly in an urban area, may be adequate, the success of rehabilitation treatment is directly correlated
to the frequency and duration of rehabilitation exercises, many of which much be done by the patient independently, between visits to the occupational therapist. Telerehabilitation is often described as having three primary components [5]:

1. Training and Counseling
2. Assessment and Monitoring
3. Point of delivery

Earlier work on telemedicine to rural areas has determined that all steps are appropriate for telemedicine. This paper focuses on how telerehabilitation can be supported for urban rehabilitation patients. Additionally, we will consider environmental monitoring in support of diagnostic services, as part of a telemedicine approach.

3. Telerehabilitation

Once a traumatic injury has occurred, and the standard six to eight weeks of healing has taken place, physical and occupational therapy may be called for. Traumas such as broken bones, surgically repaired and/or replaced joints all require a series of regular visits to a therapist, as prescribed by a medical doctor.

Wireless sensing network can be used in the form of a therapeutic cover on the injured limb, with Velcro closures to hold the cover in place on the rehabilitation client’s body. Examples of this type are outlined in [6,7]. As the client executes the recommended series of movements, which are prescribed to be repeated from three to four days a week, up to four times a day, for a series of repetitions, data from the sensors as to the commencement of movement, the angle of movement, which can be calculated in relation to other sensors, and the duration of the movement, can be reported and recorded for later review by the rehabilitation specialist. This data, collected through active sensor monitoring, would provide a better understanding of the rehabilitation client’s adherence to the rehabilitation protocol and the effectiveness of the prescribed treatment.

4. Telemedicine monitoring

The rising rate of childhood asthmatic conditions is not yet well understood. There is some thought that environmental factors, such as the odors and fumes given off by synthetic materials, such as those found in new carpets, cigarettes, or household paints may trigger if not cause allergic reactions in some pediatric patients, which then leads to asthmatic conditions and attacks [8]. Medical personnel are often faced with children and adults in asthmatic crisis, which they appropriately treat, but a better understanding of the environmental factors in the home of the patient might provide an understanding. Currently, wireless sensors are used to monitor a number of environmental factors, such as tremors associated with earthquakes and beach erosion. Passive monitoring of the telemedicine client’s home environment, which might include the use of wireless sensors on the balcony or terrace of an apartment, hallway monitoring in an apartment building, or monitoring in the client’s workplace or parking garage is possible. This passive monitoring, when correlated with client symptoms, might provide information related to chronic disease management such as asthma and emphysema, as well as other allergic reactions. By reviewing the data gathered, anticipation of disease symptoms may be possible, and appropriate pro-active preventive treatments may be started.

5. Sensor networks for urban telehealth

Sensor networks have been considered for a variety of applications [9]. The low-cost, low-power, and multifunctional aspects of sensor nodes permits them to be deployed in a wide range of areas. Here, we consider an urban network environment, such as that found in a multi-story apartment building, office building, or parking garage. Other urban environments are also appropriate, but a densely populated, physically layered structure provides a sharp contrast to the telemedicine solutions designed for rural environments. Sensor networks are a vast improvement over traditional sensors, with capabilities that include sensing, data processing and communication among nodes.

Consider a sensor network, which is composed of sensor nodes. The position of the sensor nodes does not need to be predetermined or engineered in some fashion. Random deployment of the nodes makes them ideal for installation by the rehabilitation client in their home or office environment. A ‘Rehab Net’ or ‘Med Net’ in a box, suitable for distribution to patients would be ideal, consisting of a network which could be established by the rehabilitation or medical client as needed.
6. Wireless Sensor Network for Active Patient Monitoring

The active patient monitoring aspect of the sensor network for telehealth would take place during the times when the patient was performing rehabilitation exercises. As mentioned earlier, once the injury has healed, strength in the affected limbs or area must be restored. This is most commonly done by a series of progressively more challenging exercises, which, when done correctly over an interval of time, restore measurable functionality. Usually the patient must schedule an appointment with a therapist and travel to the clinical site on the appointed date and time to execute the exercises under the supervision of a licensed clinician. The strongest factors for patient absence from therapy in an urban setting include transportation problems, and the time required for travel to, participation in, and travel from therapy appointments. For a patient who has returned to work and is hoping to continue therapy, finding the time to visit a therapist three times a week for an hour or more is quite problematic.

Once an initial clinical visit is made, exercises can be conducted at home with data from the exercises collected and forwarded by the sensor network to the therapist. Our example considers an arm or leg injury, such that sensors with Velcro closures (“cuffs”) that can wrap around the limb can be used. Three to five sensors could be used, with attachment on either side of the joints (wrist, elbow, shoulder or ankle, knee, hip) providing the initial staring point. An early outline of the design of such an environment can be found in [10].

When the patient prepares to work thru a series of exercises, the Velcro cuffs can be put on and enabled. As the patient performs the exercises, which generally involve moving the limb through an angle, the sensors can calculate where they are in relation to each other. This will permit a calculation of the angle of the patient work effort to be determined, along with the start and stop time, which will provide the total duration of the exercise, in addition to the number of repetitions. Earlier work has considered the patient’s rehabilitation to be ‘computer assisted’. In contrast, here, the patient’s work can be recorded in detail, and reported to the therapist for review and assessment. Appropriate therapeutic adjustments can be made immediately, through patient-therapist communication.


The integration of the active sensor network node which records the patient behavior during therapy with a passive environmental monitoring node, an approach which has not been suggested prior to this, would provide the most complete picture of the total environment in which the patient exists. The passive monitoring devices could be inexpensively and easily deployed within the patient’s home and office environment. This would provide information regarding sound, toxins, and other environmental measures which might impact the patient’s physiological state, including heart beat and blood pressure, as well as alerting health care professionals and environmental authorities to excessive measurements or unhealthy thresholds.

Active sensor information refers to dynamically calculated information, such as respiration rate or a heartbeat calculation. Passive sensor information refers to statically measured information, such as temperature, humidity, or other atmospheric measures. In the event that an active sensor report merits further understanding, an assessment of the passive sensor report might be necessary. For example, if an active sensor detects an individual’s breathing rate has increased, atmospheric sampling by a passive sensor network node may illustrate that pollutants are present and preventive action should be taken to prohibit the individual experiencing an asthma attack. Alternatively, the passive sensor network node might indicate nothing extraordinary, and a follow-up active sensor measurement may support this, as the respiration rate would have returned to normal levels.

If desired, passive environmental monitoring could be done independently of the more active rehabilitation monitoring, but in the presence of chronic conditions, such as those found in urban areas, including emphysema and asthma, passive monitoring correlated with active monitoring might provide information in advance of a patient health crisis.

8. Wireless Network Application Integration

Current research efforts are addressing the integration of the active and passive monitoring environments. Several earlier efforts have addressed the active monitoring environment [11,12,13], but not to the diagnosis level foreseen here. Additionally, the integration of environmental information and therapeutic information is unique. Earlier work on
network management agents [14,15] is applicable here, including monitoring, integrating passive data (environmental monitoring) and active data (patient monitoring), filtering and forwarding, for review and archiving.

Early efforts to develop a wireless sensor network, composed of nodes designated as either ‘active’ or ‘passive’ has been positive. From a modeling perspective, active nodes and passive nodes differ only in the sampling rates assigned to them and the feature sets available to each.

Active wireless sensor network nodes sample data more frequently and are capable of performing calculations to determine if the data just gathered is significant. This is done by comparison with either a benchmark value shared by another network node, to be used for comparison, or historical values retained for comparison. Due to the resource constraints of wireless sensor network node architecture, very little information is stored locally, except as needed, and this information can be refreshed or updated as needed, if network conditions or alarm thresholds change.

Passive wireless sensor nodes sample data less frequently, and generally do a time-comparison, looking for extreme deviations from an earlier sample, most often 24 hours earlier. The previous sample is rarely of immediate interest, as passive sensor nodes are most often used to track changes over 24-hour time periods.

The wireless sensor network topology which is most often considered for urban telehealth wireless sensor network management is that of a residential apartment building. The common areas, including hallways, stairwells, lobby, and balconies, would be fitted with passive sensors, as would the residential homes. The active sensors could be worn by individuals, or placed in areas which would provide the data needed for the active wireless sensor node samples. For example, if one concern was air quality on the exterior of a building, passive sensor network nodes could be placed in appropriate locations. Additionally, if the concern was further expressed that large truck traffic through the area, which could be measured by the vibrations to the sidewalk and roadway, was extremely heavy at times, this could be determined by measuring the vibrations experienced by the sidewalk and roadway surrounding the residential apartment building, and correlating this, by timestamp or other mechanism with passive environmental samples taken during the same timeframe. This would permit review and counting of the number of large trucks, and a correlation with air quality during the time when the trucks were passing. This would quantitatively determine if there was a correlation between air quality and large truck traffic near the residential apartment building.

Predictive uses of wireless sensor networks for urban telehealth are expected to provide the most benefit. Many chronic diseases have specific symptoms which precede an attack. Active and passive monitoring would permit comparison of the current personal environment surrounding an individual to be compared with the disease attack profile and if correspondence between the symptoms observed and the symptoms which precede an attack are found, appropriate preventive actions can be taken to avoid or diminish the severity of the anticipated attack.

The anticipated benefits to urban telehealth are significant, as the resulting system is expected to be easy to use, low cost, and reliable.

9. References


