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Wireless Sensor and Actuator Networks Communication at the Mechatronic Application

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Abstract: Definitely, mechatronic applications have been widely utilized in factory automation, space exploration, military service and even in our daily life. Traditionally, various control methods have been used for this kind of application such as radio, microwave, computer networks etc. The Internet is a dominating medium of communication and the Internet-based teleoperation of mechatronic systems is coming of age. Wireless Sensor and Actuators Networks (WSANs) are performing myriad functions and presenting enormous utilities. Generally, this paper is wanted to identify the problems and issues related to the Internet-based mechatronic applications which were used WSANs.

Key words: Telerobotics applications · Wireless sensor actuators networks · Internet-based control · Ad-hoc network · Time delay control

INTRODUCTION

Wireless Sensor and Actuator Networks (WSANs) are an exciting development with a verity of large applicable potential with significant beneficial impacts on mechatronic applications. These applications can be designed using componential architecture which consists of *Network-Centric*, *Date-Centric* and *Communication-Centric*. Actually, these parts have significant interconnections via transducers and protocols like *IEEE 1451 Standards* [1,2,3]. This *unified framework* can be used in different Mechatronic applications.

These systems have been using the remote control methods like radio or microwave. Moreover, the Internet has revolutionized the way where we receive information and interact with the wide world. Thus, the Internet can be well poised to be a major communication medium for facilitating teleoperation. *Uncertain time delay problem*, *the latency*, *the uncertain data loss problem* and *data transmission security problems* are the most significant challenges. There have been myriad implementations by individual group to solve specific problems or to reduce particular barriers to deploying the telerobotics applications. This lack of common approach leads to varied efforts, which provide partially superfluous solutions. The lack of familiarity with unique methods or framework intends to deploy the telerobotics applications [4].

We had a survey to identify the problems and issues in the *Internet-based control mechatronics application* that were used WSANs. There is a necessary need for general framework, which would incorporate architecture with the aim of reducing the barriers to deployment. *Security*, *protocol* and *communication* issues should be considered in the sort of architectures. Therefore, generally the main goal is to extend the range at which mechatronic systems can be manipulated for deployment with an Internet communication in wireless environments.

Generally, the rest of this paper is organized as follows. Section 2 introduces the motivation of this research and Section 3 describes the Internet-Based application. Section 4 classifies the wireless networks. The available communication technologies for sensors and actuators networks are explained at Section 5. The communication architecture goals and implementation, the Internet time delay control architecture are described at Section 6,7 respectively. Section 8,9 discuses the characteristic feature of wireless ad-hoc network, the architecture design consideration in wireless ad-hoc network, respectively. Finally, some of resolution of identified problems and issues are presented in Section 10.

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MATERIALS AND METHODS

Recent advances in object-oriented, client/server technologies and *the Internet* are supplying the technology enablers needed to provide a uniform information architecture that can be used to build software or hardware architecture allowing the inter-operation and integration of a wide set of mechatronic applications.

A PC-based CNC (Computer Numerical Control) drilling machine [5] developed at a department of engineering, by adding a web-based interface to allow clients to remotely access and control the drilling machine via the Internet. Some examples of applied projects are: CyberCut [6] which uses webCAD and process planning in allowing users to have finer control in product design in terms of choosing tools, materials, tolerance and finishing, before actually manufacturing it with the CNC milling machine. The Internet Manufacturing (IMAN) [7] relies on the Internet for the implementation of distributed rapid prototyping, allowing platform independent means of remotely controlling a manufacturing process. While some researches have developed their own client-server architecture for communication, others [8] just have decided to use proprietary software like Symantec pcAnywhere™ to remotely control and monitor a given manufacturing process or maintenance operation.

Internet-based Application: The Internet-based robotics has focused entirely on the aspect of real-world mechatronic applications, namely *tele-manufacturing*, *tele-training*, *tele-surgery*, *museum guide, traffic control*, *space exploration*, *disaster rescue*, *house cleaning* and *health care*. An Internet-based Telerobotics system usually consists of a number of physical devices such as robots, cameras, sensors and other actuators. Therefore a specific network is needed to share their data based on a communication media. Therefore, the Internet can be considered as a suitable media.

Although the Internet offers a cheap and readily available communication channel for teleoperation, there are still many problems that need to be solved before successful real-world applications can be realized. These problems include its restricted *bandwidth* and *arbitrarily large transmission delay*, which influence the performance of the Internet-based telerobotics systems. Some of the implementations advocate removal of human operators from the feedback control loop and equip the robots with a high degree of local intelligence in order for them to autonomously handle the uncertainty in the real world and also the arbitrary network delay. Also an intuitive user interface is required for inexperienced people to control the robot remotely. The reliability of the system *should be guaranteed so that the Internet users can access the Internet robotic system 24 hours a day with minimum human maintenance*. To cope with *the low bandwidth* and *high latency imposed* on the Internet-controlled robots, there is a need to make trade-off when sending information across the Internet robotic system.

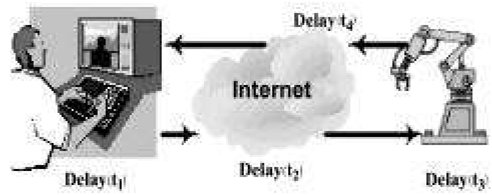

Fig. 1: Controlling an Internet-enabled arm robot in an open control laboratory

Generally, the Internet-based robotic teleoperation involves controlling robots from a web browser remotely and varies from traditional robotic teleoperation in several aspects:

- The delay and the throughput of the Internet are highly unpredictable, unlike traditional teleoperation (for example space-based and underwater) where the interfaces have fixed and guaranteed delays.

Generally, Figure 1 addresses the Internet time delay, the user interface design and concurrent user access for an Internet-enabled arm robot. The implementation and application of the Internet-enabled arm robot in an open control laboratory is illustrated as a case study [9].

- Web-based teleoperation requires a high degree of tolerance to possible data-package loss due to packet discard when there is no existing remedy.
- The Internet robots need innovative mechanisms for coping with shared control among multiple web users with different applications in mind.
- Since web users are a central part of the control loop in Internet robots, their behavior becomes an important consideration in the system design [10].
- The Internet robots are remotely operated by many people with little expertise and few skills. In contrast, traditional tele-robots are handled by trained operators [11].

Classification of Wireless Networks: Generally, wireless networks can be broadly classified into *Data-centric networks* and *Communication-centric networks*. Wireless LAN and the Sensor network are two typical examples of Data-centric networks. In this type of network efficient routing of data takes preference. The examples of Communication-centric network are the Cellular networks, Ad-hoc Robotic networks and also Mobile Ad-hoc Networks (MANETs). The realization of the sensor network applications need wireless ad-hoc networking techniques. The environment in which these sensor networks are deployed could be in remote geographical areas for the purpose of habitat monitoring. Hence it is self-evident that replenishment of power resources might be impossible or impractical. Therefore, such sensor networks could be deemed as limited in power resources. So, the sensor node lifetime shows strong dependence on battery lifetime. Consequently, in such networks power conservation and power management takes precedence over other factors.

On the other hand in case of MANETs the power conservation is of secondary importance since replenishment of power is viable. Hence in MANETs and especially in Ad-hoc robotic networks, the primary focus is on provision of high quality of service (QOS) and also on bandwidth efficiency. This is apparent because the MANETs and the ad-hoc robotic networks are considered as Communication-centric networks. Moreover, the MAC protocols used in MANETs cannot be utilized directly for sensor networks. Thus the sensor networks would need energy optimized MAC protocol.

Communication Technologies Available for Sensor and Actiators Network: Conceptually, the communication within a sensor network can be classified into two categories: *Application* and *Infrastructure*. Application communication relates to the transfer of sensed data (or information obtained from it) with the goal of informing the observer about the phenomena. Within application communication, there are two models: *cooperative* and *non-cooperative*. Non-cooperative sensors do not cooperate at the application level for information dissemination. One extreme case is where no sensor communicates with its neighbors- all the sensors work independently and continuously relay sensed data to the observer. In the second case, cooperative sensors, a given sensor might be required to communicate with its neighbors either periodically or after the occurrence of a specific event. An example of co-operative sensing is in a clustering protocol when a cluster-head and the non-cluster-head members communicate with each other for information dissemination related to the actual phenomenon.

Definitely, the infrared technology is being primitively applied in large scale in wireless mechatronic communication mainly due to its low cost. Study shows that there are drawbacks to this technology which include failure to pass through obstacles (e.g. wall), poor communication rate and quality. Radio Frequency (RF) technology is found to be better for mobile robot communication. Robots are able to communicate in the system using RF point-to-point or broadcasting mechanism. The Frequency Hop Spread Spectrum (FHSS) and Direct Sequence Spread Spectrum (DSSS) modulation technologies are being widely applied at the ISM (Industrial Scientific Medical) band (2.4GHz), which is license-free in several countries. The proliferation of the Internet-based networks has given rise to application of Wireless LAN (IEEE 802.11, used in both infrastructure and ad-hoc network), Bluetooth standards for ad-hoc networks and Ultra-Wide Band (UWB) radio.

Generally, in the robotic teleoperation architecture, the technology employed is the 802.11b [12]. The reason being that in robotic teleoperation the wireless technology does not play an important role and a choice of high data rate wireless technology is sufficient. The wireless link is a facility to provide mobility to the robots operating in the robotic teleoperation architecture. Therefore, looking at the requirements and the economic aspect, the 802.11b standard is chosen as the underlying technology for the robotic teleoperation.

In the ad-hoc robotic network, the main concerns are *bandwidth efficiency*, *high throughput* and *low delay* [13]. In other words the focus is on high QOS. For this purpose, the UWB is the most ideal wireless technology available. But currently, UWB only supports short-range networks due to the power level restrictions imposed by the FCC. Short-range level is totally unacceptable for ad-hoc robotic networks which may have to be remotely controlled for distances which far more exceed 10 meters. This is due to the fact that ad-hoc robotic networks are envisioned to be operated in alien environments and situations where the knowledge of the habitat in which the robots will operate is unknown. Therefore, there is an obligation to provide as much remote mobility for the robots by way of facilitating maximum wireless range possible. Hence, the current UWB implementation is not feasible. So the search for another technology which provides better range and the other requirements is the 802.11b standard. This standard has the ability to provide multi-hop communication required by the ad-hoc robotic network. Also the bandwidth and throughput requirements are fairly good. Moreover using the 802.11 b standard, facilitation of Internet service to the network is convenient with the use of ad-hoc wireless bridge. Hence 802.11b is employed as the wireless technology for the ad-hoc robotic network.

Generally, in the sensor networks due to the power conservation aspect, the UWB would have been the ideal technology since UWB can efficiently operate in low power levels. But again the short-range factor of UWB comes to haunt. Sensor networks are put in service in remote environments for habitat and crop monitoring, which calls for long-range, network deployment. Hence it is infeasible again to use the current implementation of UWB in sensor networks. So the next available technology is the 802.11b standard. Due to the employment of 802.11b though, there would a dire need to implement an energy-optimized design of MAC protocol.

Common Architecture Goals and Implementations Generally, There Is Common Architecture Goals and Implementation:

- It is necessary to provide a user-friendly web-based user interface in order to facilitate users with little expertise in operating and controlling remote robots.
- The robots employed here are considered to be 'slave' robots with no local intelligence. Hence the control mode operation is the direct control. This signifies that direct control allows the user/operator low-level control of the robot. This brings to focus the need for architecture, which should be insensitive to the Internet delays. Therefore, the Internet delay control architecture is employed.
- It is suggested to provide better transmission protocol for speedy data transfer over the Internet. Focus should be on on-time delivery rather than reliable delivery. This is because reliability causes unbearable delays. TCP is designed for reliable data communications, on low bandwidth, high error rate networks. On the other hand, UDP is a connectionless datagram delivery service. Generally, UDP supplies minimized transmission delay by omitting the connection setup process, acknowledgement and retransmission. Hence, UDP outperforms TCP in terms of delay and delay jitter. Thus from the point of timeliness and on-time delivery view, UDP is more suitable for delay sensitive data transmission of the Internet-based robotic teleoperation.
- It is recommended to employ 802.11b standard for wireless link between the robot and the robot server. Here, the backbone communication topology supported by 802.11 standards is put in to service. So, this implies that the robot will communicate wirelessly via the access point, which is the robot server in this case.
- Implementing security feature is an important issue to ensure the safety of the robot from malicious users and hackers. This is accomplished by providing login service in the web server. Generally, this facility will help to set the authority level for access. So, due to the use of 802.11b for wireless data transfer between the robot server and the robot, Wired Equivalent Policy (WEP) encryption technique associated with 802.11 will need to be implemented for security from "wireless hackers". Thus, WEP is used in 802.11 networks to protect link-level data during wireless transmission from eavesdropping and other attacks

The Internet Time Delay Control Architecture: The Internet time delay control architecture is designed to minimize the effect of the Internet time delay. The Internet time delay control architecture consists of a *user interface*, *simulator*, *virtual habitat* and *posture calculator*. The robot simulator is like the virtual mobile robot, which is at the local side. Posture calculator estimates the current posture of the virtual robot based on the feedback information of the real robot. Figure 2 is illustrated the classified robotic teleoperation architecture [10].

Posture calculator corrects the error between the real robot and the virtual robot. Virtual habitat has the information of the real habitat so that it enables the virtual robot to avoid obstacles. In order to correct the posture error between the virtual robot and the real robot, the real robot generates feedback signals such as posture information of the real robot, to the simulator [14].

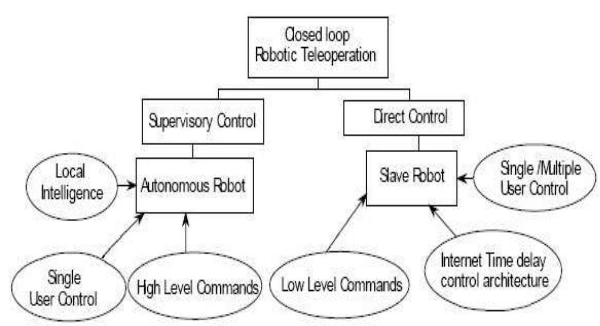

Fig. 2: Classified robotic teleoperation architecture

Direct Control Robotic Teleoperation: To cope with the Internet delay through the implementation of the Internet delay control architecture. This aspect has to be kept in mind due to the fact that in this particular scenario robotic system is directly controlled over the Internet and the robots used are lacking autonomy and local intelligence. In short the robots are assumed to "slave" robots. At the same time the robot is assumed to be possessing obstacle avoidance capability in order to prevent damages to the robot and also the surroundings. This capability is essential in the eventuality of overall system failure. In this case the user/operator has to supply low-level commands to control the robot. Such type of control is termed as the direct control robotic teleoperation.

Supervisory Control Robotic Teleoperation: In the other scenario when an autonomous robot is used, the Internet transmission delay is not an issue because the robot through its local intelligence like collision avoidance, path planning, self-referencing, object recognition etc. has the ability to protect itself and its environment. In this case the user/operator has to furnish high-level commands to control the robot. Such type of control is termed the supervisory control robotic teleoperation.

Characteristic Features of Wireless Ad-hoc Network: An ad-hoc network is formed by a collection of network nodes with wireless communication capability. It does not rely on central entity or infrastructure (e.g. base station or access point) for communication. Two nodes can communicate directly if they are within radio range of each other. If out of range, the nodes can communicate through one or more intermediate nodes. In such a case, the intermediate nodes act as routers and relay packets from the source node to the destination node.

Generally, most ad-hoc networks include nodes that have limited resources typically limited battery life. Therefore, such networks can be termed resource-constrained networks. The topology of an ad-hoc network changes dynamically due to nodes changing their point of connectivity. The topology changes as nodes move out of range of one or more nodes with which they are connected and move closer and connect to other nodes. Thus in an ad-hoc network, the topology has to undergo frequent changes. In ad-hoc networks, nodes have to play multiple roles like being both the host (source or destination for data flow) and also as router. In other words, the nodes are expected to route packets for other nodes in the network while they themselves may be a source or destination for data flow. Thus the architecture must account for the multiple roles played by the robot nodes. Hence, the focus of the architecture should be efficient protocol employment in ad-hoc robot network.

Generally, routing algorithms can be classified based on their method of routing table maintenance, which is either *Table-Driven* or *On-Demand*. Therefore, *Proactive* or *Table Driven* protocols are analogous to the connectionless approach to packet forwarding. All nodes in the network are made aware of all the routes leading to all other nodes in the network. *Reactive* or *On-Demand* routing techniques wait for a route to be requested before it will form, causing a node to delay packet transmission until the route has been established thus resulting in packet delay. Definitely, On-Demand routing attempts to find the best path from source to destination immediately prior to message transmission. As a result, this method does not incur extensive signaling overhead associated with routing table formation but imposes a delay on each message transmissions as paths are established. On the other hand, Reactive protocols are either source initiated or destination-initiated. Since Ad-hoc networks are assumed to be energy constrained, this delay is acceptable as the signaling overhead and power consumption is reduced due to routing information propagation.

Proactive or Table Driven routing protocols such as Direct Sequence Distance Vector (DSDV) require each mobile node to maintain and update routing tables to all nodes within the network. In reactive protocols such as Ad-hoc On-Demand Distance Vector (AODV), the source node initiates a path discovery process, by flooding a control message when a data message is sent. The recipient then replies to the sending node with the optimal path formation. AODV is thus termed a source-initiated reactive protocol. Proactive routing protocols can be deployed in a small size and slow topology-changed network. Reactive protocol may be more suitable for a large scale and fast topology-changed network. Latest protocols have indicated a combined use of both proactive and reactive methods. Generally, Zone Routing Protocol (ZRP) proposes that table driven methods can be used to route packets from zone to zone within the network with inter-zone routing carried on a demand-only basis. ZRP is conducive for large networks. The large network can be divided into small subnets. The proactive component of ZRP can be used in subnets while reactive component can be used among subnets [15,16,17]

Architecture Design Considerations in Ad-hoc Networks: The following are the architecture design considerations in ad-hoc networks.

- It is better to select a suitable protocol in the transport protocol layer, which is suited to work better in the ad-hoc robotic network. *Research says that TCP does not perform well in ad-hoc networks*. UDP works better in ad-hoc networks. Therefore, UDP is employed in the underlying architecture. UDP is a simple transport protocol, which makes it faster than TCP since it imposes lesser overhead to each packet.
- It is recommended to use efficient ad-hoc routing protocol for routing packets between robots in the ad-hoc zone. This need calls for a protocol designed for mobile ad-hoc networks. There are several ad-hoc routing protocols, which are either proactive or reactive protocols. An example of proactive protocol is the Optimized Link State Routing Protocol (OLSR) and that of reactive protocol is AODV protocol. A hybrid protocol namely ZRP is a protocol typically designed for mobile ad-hoc networks. It is a hybrid protocol that is part proactive and part reactive. The proactive part is called *intrazone routing protocol* and the reactive part is called the *interzone routing protocol*. Therefore, the ZRP is employed in the architecture for overall system gain.
- Generally, the MAC protocol redesign with the high QOS requirements under consideration. The high QOS would signify the high throughput and low delay. This is an essential requirement because the architecture is being formulated for the ad-hoc robotic network, which is a communication-centric network. Though energy conservation is of secondary importance as opposed to sensor network where it is of prime importance, it is still an entity to be considered while the design of the MAC protocol along with the high QOS [18].

Protocol Layers in the Extensive Ad-hoc Robotic Network: The different protocols pressed into service for the underlying architecture are as follows.

- A modified 802.11 MAC, which incorporates energy efficiency. The hidden node problem is also typical for nodes operating in the ad-hoc networks. Hence stress should be on to overcome the hidden node problem. Hence the 802.11 MAC needs to be designed taking into consideration these major issues.
- UDP, which works in the Transport layer. UDP has been found to work better in ad-hoc networks. This protocol immensely helps to reduce overhead.
- IP, which works in the Network layer. IP is assigned with routing packets through the Internet. It can also fragment datagram to meet local size requirements and also reassembles them at the destination.
- ZRP, which resides in the Network layer along with the IP in the robot nodes. ZRP is a suitable hybrid protocol for ad-hoc networks hence this protocol is employed.

Resolution of Identified Problems and Issues: The following are the identified problems and issues along with the resolution.

Security: The WEP is used in 802.11 PHY based networks to protect link-level data during wireless transmission from eavesdropping and other attacks.

Fault Tolerance: The sensor nodes may fail due to lack of power, physical damage or habitat interference. The failure of sensor node should not affect the overall performance of the network. This is the reliability or fault tolerance issue. Fault tolerance is the capability to persist sensor network functionalities without any interruption due to sensor node failures. The decentralized approach followed in the sensor network architecture is expected to cope with the node failure problem.

Power Conservation: Power efficiency directly influences the network lifetime in a sensor network and is of pivotal importance. Due to the fact that sensor networks are highly energy constrained, the battery reserves cannot be feasibly replenished. Hence power conservation is of importance in order to prolong the network lifetime in a sensor network. Power conservation is achieved through random wake-up schedule during connection phase and turning the radio off during idle time slots. Another paradigm for power conservation in sensor networks is "data aggregation" whereby data coming from different sources is combined and routed to single destination along with elimination of redundancy and minimization of the number of transmissions thereby saving energy.

CONCLUSIONS

WSANs represent a new generation of real-time embedded system with significantly different communication in the mechatronic applications. WSANs are being created to be able to connect wirelessly and use minimal power. Providing Internet access to these sensors/actuators operating in the ad-hoc network is an excellent way to make them ubiquitous. These sensors apart from being able to exchange messages within the ad-hoc networks would also facilitate message exchange with the Internet nodes with the help of sink. These sensors run ad-hoc routing protocol to route packets within the sensor cluster or zone. They also run the wireless protocols designed for communication through the wireless channel. At the same time, Internet nodes also use this wireless protocol for communication with the sensor nodes through sink.

Generally, the Internet-based control systems use the Internet for remote control and monitoring of plants. Although the Internet offers a cheap and readily available communication channel for teleoperation, there are still many problems that need to be solved before successful real-world applications can be realized. These problems include its restricted *bandwidth* and *arbitrarily large transmission delay*, which influence the performance of the Internet-based telerobotics systems the Internet time delay, the user interface design and concurrent user access for an Internet-enabled arm robot.

The problems and issues concerning the sensor network are dealt with the help of respective implementations in the sensor network architecture. The sensors acting in the network are “smart sensors” with ability of *sensing*, *computing and communication*. Such sensors deserve to be accessed globally by remote users in particular. Hence Internet connectivity to these sensor networks is of prime significance. So the architecture for the sensor network tries to achieve this goal along with other necessary system gains. The key problems and issues include the *energy constraints of the sensor network*, *fault tolerance* and *the security*. The power constraint problem is taken care by the employment of energy efficient MAC protocol design and also through other strategies for conservation of energy. The fault tolerance is incorporated inherently with the decentralized model of the architecture. The security issue is handled with the use of WEP encryption policy in the 802.11 standard to protect against link level attacks.

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