Mobile Robot Communication Without the Drawbacks of Wireless Networking

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Abstract. The default solution for mobile robot communication is RF-networking, typically based on one of the IEEE 802.11 standards also known as WLAN technology. Radio communication frees the robots from umbilical cords. But it suffers from several significant drawbacks, especially limited bandwidth and range. The limitations of both aspects are in addition hard to predict as they are strongly dependent on environment conditions. An outdoor RF-link may easily cover 100m over a line-of-sight with full bandwidth. In an indoor environment, the range often drops to a few rooms. Walls made of hardened concrete even completely block the communication. Driven by a concrete application scenario where communication is vital, namely robot rescue, we developed a communication system based on glassfibre links. The system provides 100MBit ethernet connections over up to 100m in its default configuration. The glassfibres provide high bandwidth, they are very lightweight and thin, and they can take a lot of stress, much more than normal copper cable. The glassfiber links are deployed from the mobile robot via a cable drum. The system is based on media converters at both ends. One of them is integrated on the drum, thus allowing the usage of inexpensive wired sliprings. The glassfibre system turned out to be very performant and reliable, both in operation in the challenging environment of rescue robotics as well as in concrete experiments.

1 Introduction

Though there is some work where even cooperative robots are investigated without communication [Ark92], there are hardly any application scenarios where mobile robots can really operate without being networked. The common technical solution is the IEEE 802.11 family of standards also known as WLAN [OP99]. WLAN has its well-known limitation [PPK+03], especially in respect to bandwidth and range. One simple remedy is to use mobile robots to act as relay stations along a kind of bucket brigade [NEMV02, NPGS03]. In doing so, the relay robots follow a lead robot and they stop when the communication chain is threatened to be broken. The big disadvantage is that rather many robots are needed to cover extended areas and that the majority of the robots is used for nothing but as a communication relay. More complex variations of the relay idea

A. Bredenfeld et al. (Eds.): RoboCup 2005, LNAI 4020, pp. 585–592, 2006.

are investigated in the field of ad-hoc networking [Per00] where dynamic links and routing protocols are employed [JMH04, RT99, JW96].

In addition to the severe limitations in respect to bandwidth and reliability, wireless communication solutions have the significant drawback for rescue applications that they block parts of the precious RF space. Rescue missions involve different groups of first responders like firebrigades, police, medical doctors, and so on. Each of these groups has their own communication systems. For many large scale disasters like earthquakes, there are even many of these groups from different countries, each with its own type of communication equipment. The coordination of the usage of RF bands is a known problematic issue at disaster sites. Any additional system like a rescue robot will face difficulties of acceptance if it will block parts of this scarce resource with its wireless network.

Here, an extremely simple new approach is taken that circumvents the core underlying troublemaker, namely the usage of RF as medium for mobile robot communication. Instead, glassfibres are used. Being a cable based medium, the challenge is to find a suited approach to deploy the cables during operation by the robot itself. For this purpose a low-cost cable-drum system was developed, which has proven to be very versatile and stable.

The rest of this paper is structured as follows. Section 2 gives an overview of the system. Experiments and results are presented in section 3. Section 4 concludes the paper.

2 System Overview

As mentioned before, the quality of RF-communication strongly depends on environmental conditions. We are interested in a particularly harsh domain, namely rescue missions where robots are operating in urban disasters scenarios ranging from earthquakes to gas or bomb explosions [RMH01, Sny01]. Distortions or even complete failure of RF-communication is a known problem in the according

Fig. 1. A rescue robot with the glassfibre drum on its back (left). It has to operate in an environment where high mobility is needed and the glassfibres are experiencing a lot of stress through obstacles (right). Nevertheless, the glassfibres never failed in over two years of operation.

scenarios when RF-transceivers are moved through partially or fully damaged buildings. In addition, RF bands are a scarce resource, which may only be used under very special permissions at large scale disasters like earthquakes. We therefore developed an alternative solution to RF to allow for high bandwidth communication of mobile devices.

The goal of the IUB rescue robots team is to develop fieldable systems within the next years. Since the beginning of its research activities in this field in 2001, the team has participated in several RoboCup competitions to test its approaches [Bir05, BCK04, BKR+02]. In addition to work on mapping [CB05] and adhoc-networking [RB05], the development of the robots themselves based on the so-called CubeSystem [Bir04a] is an area of research in the team [BKP03, BK03].

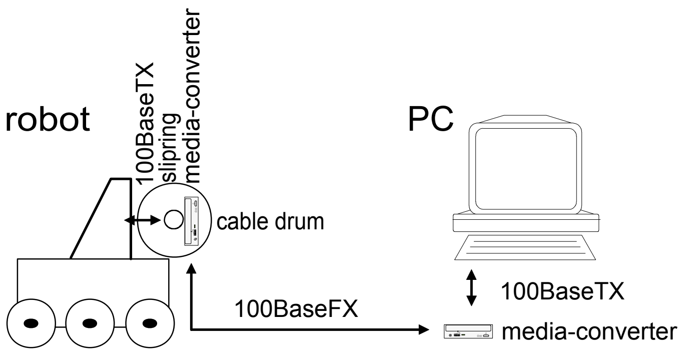

Fig. 2. The components of the deployable glassfibre communication system. The overall system behaves much like a standard 100BaseTX FastEthernet connection between the robot and an endpoint like a PC (cross-cable connection) or a network bridge (straight-cable connection).

Figure 2 shows the main components of the overall system:

- two Allied Telesyn AT-MC100 media converter
- one IDM Electronics H6 slipring
- 30m to 100m of monomode glassfibres

Glassfibres are preferable over copper as cable medium for several reasons. First, they are lightweight. For our application purposes in the order of a factor two to three when compared to copper cable. Second, the bandwidth/distance parameter is much higher [YZ01]. Third, glassfibers are much less vulnerable to physical stress than normal CAT5 cables. This holds especially in respect to the minimum bending radius. This parameter is of quite some importance in application scenarios where high agility is a must. This robustness of the glassfibres in our system has been proven in uncountable testruns of our robots in the IUB rescue arena [Bir04b] as well as in various RoboCup competitions including RoboCup 2003 in Padua, RoboCup American Open 2004 in New Orleans, RoboCup 2004 in Lisbon and the RoboCup German Open 2005 in Paderborn.

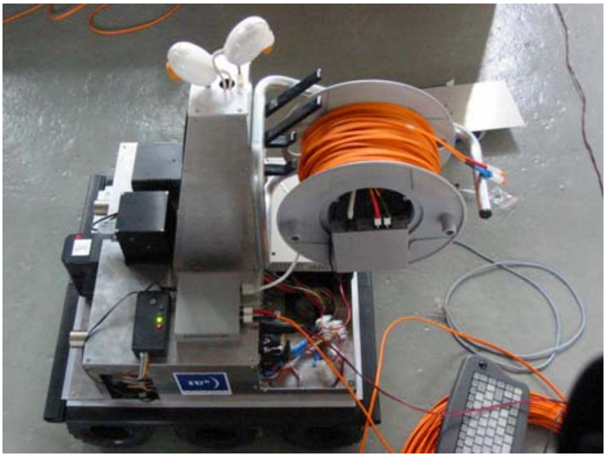

Fig. 3. A rescue robot with the newly designed cable deployment system

Fig. 4. A close-up of the cable deployment system

In none of the testruns or competitions did the glassfibre based communication system ever fail.

As the cable is to be deployed from the robot, a rotating joint is required. The usage of very expensive optical sliprings could be prevented by a simple trick, namely using standard media converters. On both end points of the communication system, 100BaseTX FastEthernet connections via a standard RJ45 connector are provided. 100BaseTX uses Category 5 cabling, or simply Cat5. Cat5 is a type of cable designed for high signal integrity - it is tested to insure a clean transmission of 100Mhz signals. The size of each wire is 22 gauges and each pair of wires is twisted within the exterior cladding, thus the name "twisted pair" which refers to this type of cabling. As there is no shielding around the four twisted pairs, Cat5 is generally referred by the term "unshielded twisted pair", or simply UTP.

100BaseTX uses only two of the four available pairs of UTP cable. One pair(TX) is used for transmission and the other(RX) is used for reception. The

TIA-568B wiring standard defines the color-coding and, most important, the order of wires' connection in a RJ-45 8-pin modular jack. The so-to-say spare wires on the cable are used in our system to power the media converter on the cable drum.

So, the overall system mainly consists of a conventional 100BaseFX glassfibre communication part, which is converted at both end points to a 100BaseTX copper cable. The unconventional part is the 100BaseTX link on the robot, which connects its network card with the media converter on the cable drum via a wire slipring.

3 Performance of the Cabledrum

The potentially error-prone part of our system is the unconventional 100BaseTX cabling involving a lowcost slipring. There are several crucial parameters for CAT5 cable, namely

- *Attenuation* is the decrease in signal strength along the transmission line. Since digital signal processing cannot significantly compensate for signal degradation, ensuring low levels of attenuation is crucial.
- *Attenuation to crosstalk ratio(ACR)* is the difference between attenuation and near-end crosstalk(NEXT). ACR is a crucial calculation with regard to network transmissions. Its positive values ensure that a signal transmitted along a UTP cable is stronger than near-end crosstalk.
- *Near-end crosstalk(NEXT)* measures the undesired signal coupling between adjacent pairs at the transmit end.
- *Far-end crosstalk(FEXT)* measures the undesired signal coupling among adjacent pairs at the receive end.
- *Equal level far-end crosstalk(ELFEXT)* is obtained by subtracting attenuation from the far-end crosstalk. Poor ELFEXT levels can result in increased bit error rates and/or undeliverable signals.
- *Propagation delay* is the amount of time the signal travels from the transmit end to the receive end.
- *Delay skew* represents the difference between the pair with the highest propagation delay and the pair with the lowest propagation delay.

There exist very strict limitations for these parameters [KBs, Ryb99]. As the low level electrical properties of the slipring are neither documented nor easy to measure, it is hence necessary to make a more high level investigation of the properties of this link. Note that the usage of standard network test equipment is not necessary helpful as the low level parameter of the slipring strongly depend on its mode of operation, i.e., on its rotation rate. So, there is the need to evaluate the deployable glassfibre system in respect to its compliance with the ethernet standard.

The study of network transmission quality is a significant field of research dealing with various metrics [Dre02, Fer90, Dre03]. Here, we simply measure the round trip times of network packets to test the quality of the cabledrum

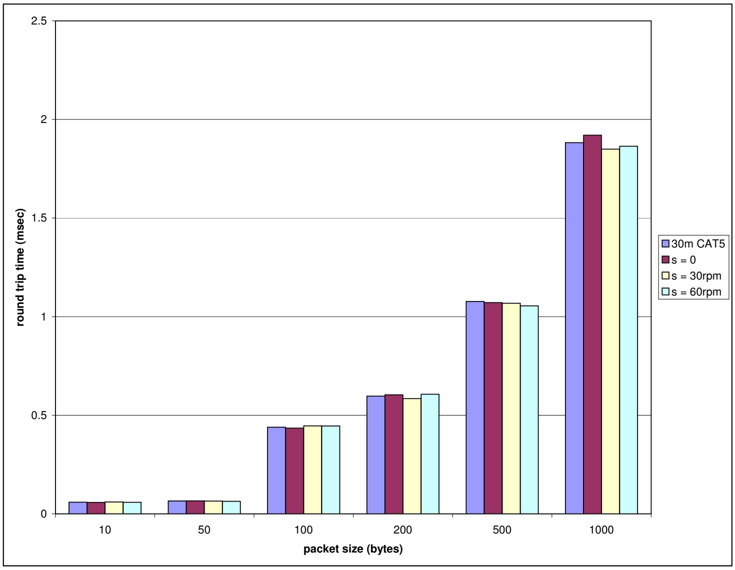

Fig. 5. The average round trip times (RTT) of 1 million packets measured over a standard 30 meter CAT5 cable as well as over the IUB cabledrum rotating at no (s = 0 rpm), medium (s = 30 rpm) and high speed (s = 60 rpm). The RTT only depend on the packet size and slight random variations. No significant differences between the standard cable and the drum rotating at different speeds can be measured.

system. To measure the potential problems caused by the slipring, the short 100BaseTX link from the robot card to the media converter via the slipring is compared to a 30m standard CAT5 cable, i.e., a standard medium length copper cable compliant to 100BaseTX. The cabledrum is furthermore rotated at different speeds to test whether the transmission quality is influenced by this. As shown in figure 5, a difference between the standard patch cable and the cabledrum can not be measured in any of the experiments. This holds in respect to reliability, which is always perfect with 0% packet loss, as well as in respect to average round trip times (shown in figure 5) and jitter. The overall system with 100m glassfibres behaves thus like a direct 100BaseTX FastEthernet connection between the robot and an endpoint with completely neglectable delays from the media converters.

4 Conclusion

When it comes to mobile robot communication, wireless networks are the overwhelming standard. We have shown that a cable based approach can be a serious alternative, especially for RoboCup Rescue. A deployable glassfibre system was presented which has proven to be reliable in the field as well as in experiments. Glassfibres are lightweight, thin, and very robust. Furthermore, they carry high data rates with low delay and high reliability. The need for an expensive optical slipring is circumvented in our system by using media converters. One of the converters is on the cable drum. This allows a 100BaseTX copper wire connection from the robot's network card via a simple wire slipring to this media converter.

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