EPiC Series in Health Sciences
Volume 7, 2024, Pages 226–231
Proceedings of The 24th Annual Meeting of the International Society for Computer Assisted Orthopaedic Surgery

A modular wireless tracking system as central service provider in the operating room using ISO IEEE 11073 SDC

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Abstract

In order to improve the usability of surgical navigation systems, this paper presents the design, implementation and testing of a mobile wireless tracking camera cart for intraoperative use. The tracking data, i.e., tool poses, are made available on the operating room (OR) network by means of the manufacturer-independent communication standard ISO IEEE 11073 (“SDC”). In this way, the wireless tracking system (WTS) can act as a modular localization service for various medical devices such as robots and navigation software.

The concept and implementation of the battery-powered wireless tracking cart is shown. The paper furthermore evaluates how the use of a new software library improves latency and reliability in contrast to previous implementations.

The results indicate that the new software library and the wireless data transfer do indeed meet the required latency of 50 milliseconds for hand-eye coordination tasks with a reliability of 99.395% even when the network is under OR-typical load. However, as the library does not offer any additional safety determinism, increased maximum latency times may occur in individual cases, making the device unsafe for intraoperative use.

1 Introduction

Numerous applications in the OR depend on accurate tracking data, including navigation of surgical instruments and implants, ultrasound probes (Brößner et al., 2023) or robot control (Schleer et al., 2019). Further applications include zero-dose x-ray imaging (Müller et al., 2011) or remote pointers for human-machine interaction (Janß et al., 2009), e.g. for digitizing anatomic landmarks for registration or kinematic analysis.

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J.W. Giles and A. Guezou-Philippe (eds.), CAOS 2024 (EPiC Series in Health Sciences, vol. 7), pp. 226–231

Most sources locate the window of acceptable latency for a surgical hand-eye-coordination task at approx. 50-100 milliseconds (Johnson, 2014; Xu et al., 2014). In robotics the critical latency may be even shorter, as the latency directly affects the speed of motion-compensation the robot is able to perform (Vossel et al., 2021) and can differ between tracking cameras (Elfring et al., 2010).

A common problem addressed in recent literature is the monolithic approach taken by manufacturers of surgical equipment, who usually include a dedicated tracking camera unit with every navigation or robot system, increasing the cost of these systems (Vossel et al., 2020). As Vossel et al. argue, tracking cameras provide utility beyond their single-system function and could become a modular accessory, making navigated surgeries more affordable whilst providing additional benefits to the staff. The manufacturer-independent communication standard ISO/IEEE 11073 SDC could provide the necessary connectivity for such a modular camera.

The results by Vossel et al. indicate that the latency of an SDC tracking camera system generally meets these requirements. However, the latency depends greatly on the remaining network load, since no prioritization for specific types of network traffic is implemented. In their experiments, a realistic scenario with contending medical devices already produced latencies which would be unacceptable for navigation tasks.

Their data indicates that a significant delay was added through the conversion of the camera data into SDC-compliant messages, produced by the middleware library *SDClib/C*. The newer library *sdcX* promises to reduce internal delay compared to *SDClib/C*.

Lastly, the issue of wired connectivity remains. Despite its advantages, the use of navigation can decrease safety and ergonomics in the OR, needing more space for the devices and adding more cable connections which may present tripping hazards and increase setup time. This increases stress levels among surgical staff. Wireless systems still take up floor space, however they can be placed and maneuvered in a more flexible way. Since tracking cameras are often repositioned during surgery to assure line-of-sight, the development of a wireless tracking cart suggests itself.

2 Materials & Methods

We use a *fusionTrack 500* camera (Atracsys LLC, Puidoux, Switzerland) connected to an x86-type embedded PC (*UP Squared 6000*) running a Linux system with the PREEMPT-RT patch applied (Gutiérrez et al., 2018). The camera is interfaced with the official *Atracsys* SDK and calculates tool poses from camera images on the PC.

For SDC connectivity, we use version 1.2 of the *sdcX* software library by *SurgiTAIX AG* (Herzogenrath, Germany). This commercial software library has been developed to power actual medical devices, even providing the necessary documentation for a Class C approval process. In contrast to the previously used *SDClib/C* library, *sdcX* has been optimized for reduced latency and improved stability.

We developed a mobile wireless tracking cart. This novel battery-powered unit operates without any cable connection. For the physical realization of the wireless tracking system, an off-the-shelf pivot arm on wheels was re-fitted to hold the *fusionTrack 500* camera. It is mounted on the swiveling arm, whereas the battery, DC/DC converter, embedded PC and PoE injector are located at the base. This gives the construction a low center of mass for easier maneuverability and does not increase the footprint of the cart.

For wireless data transmission, the embedded PC is upgraded with an *Intel AX200* WiFi 6 modem.

The camera and the embedded PC draw 31 Watts during operation. The power is supplied by an *aentron A48010M* battery with a usable capacity of approx. 860 Wh. It weighs 8.3 kg and powers the system for more than 24 hours from a full charge. Therefore, the requirements for the wireless camera in a surgical scenario are met. See the block diagram in Figure 1c).

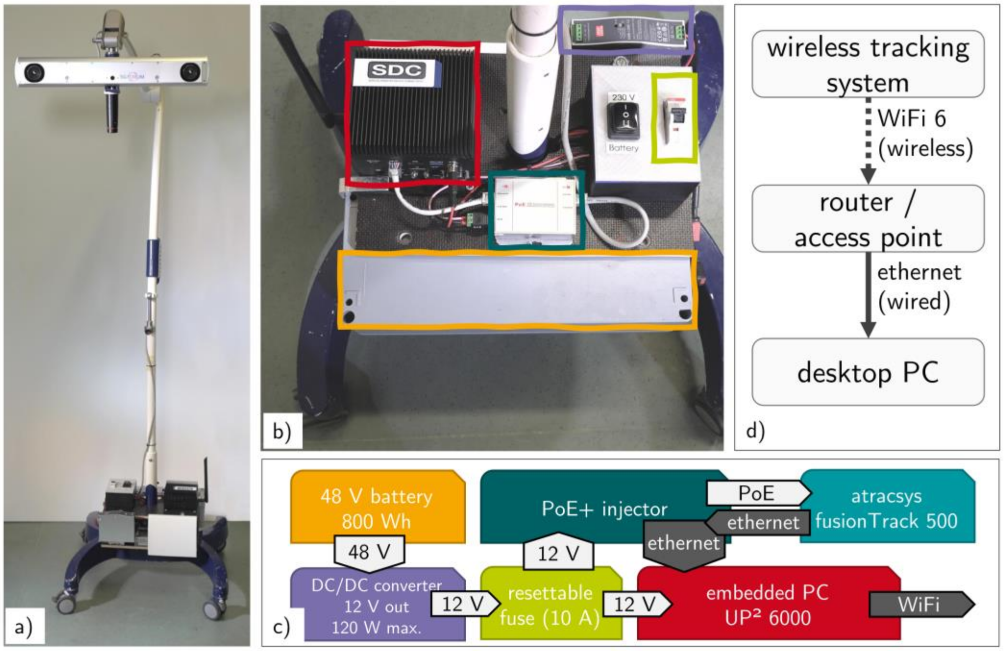

Figure 1: a) photo of the WTS, b) close-up of the base-mounted components, c) block diagram of the components (colors match boxes in b), power & data flow in the WTS, d) schematic of test setup

The system is evaluated as follows:

We measure the performance improvement provided by the *sdcX* library without any camera data processing added. A sender program on the WTS creates timestamped data packets and sends them to a receiver app on the desktop computer, where another timestamp is added and the difference is logged to a file (Figure 1d). The sender creates data at a target rate of 100 Hz and the experiment runs for 1 hour. We discard the first and last ten seconds of each measurement session in order to eliminate errors from interaction with the computers. In order to synchronize the timestamping on sender and receiver, the clocks are synchronized via *Precision time protocol (PTP)* within 1 microsecond alignment. The latency results are provided in Table 1. Experiments are carried out both via wired LAN as well as wireless WiFi transmission for comparison.

In another measurement series, there are 10 surgical SDC devices and 31 additional dummy providers on the wired network, creating competing traffic which could influence the latency of packets sent by the tracking camera. This test case is very similarly used by Vossel et al., denoted as "*busy network*" in Table 1.

3 Results

Statistics of the measured latencies have been compiled in Table 1. Our measurements include the transmission time of a numerical data point via LAN/WiFi plus the sdcX middleware. For comparison, the original values from (Vossel et al., 2020) are given. To enable a significant comparison to our experiments, the processing delay created by the tracking software has been deducted from Vossels values in the table.

Table 1: Results of one-hour latency measurements from the wireless tracking system to the desktop PC (one-way)

TEST CASE		MIN LATENCY [MS]	MEAN LATENCY [MS]	95% QUANTILE [MS]	MAX LATENCY [MS]	STANDARD DEVIATION [MS]	RELIA-BILITY (< 50 MS)
LAN	**UDP**	0.023	1.29	0.095	50.27	6.29	99.982%
WIFI	**UDP**	0.425	2.053	5.031	160.309	6.727	99.709 %
LAN	**SDClib/C** Baseline *Vossel et al., 2020* (minus tracking)	2	10.1	16	16	4	100 %
LAN	**SDClib/C** “busy network” case *Vossel et al., 2020* (minus tracking)	2	101.9	356	1180	128.7	< 95 %
LAN	**sdcX**	0.756	1.299	1.416	43.715	0.141	100 %
WIFI	**sdcX**	1.510	3.427	4.840	448.215	9.260	99.398 %
WIFI	**sdcX** “busy network”	1.537	3.387	4.438	370.487	9.782	99.395 %

The statistics generally support that the more recent *sdcX* software library provides quicker processing than the *SDClib/C*. In the 95% quantile for the wired setup, the transmission takes less than 2 milliseconds with sdcX, which is 14 milliseconds or 91% less. However, there are more extreme outliers. The maximum latency is 2.7 times higher than in the experiments presented by Vossel et al.

In the wireless transmissions, the distributions widen even more. In the worst-case, maximum latencies are ten times as high as for the wired setup. Nevertheless, 99.398% of dates are received within the 50-millisecond timeframe deemed sufficient for hand-eye-coordination tasks.

When the network is under load, the minimum latency is slightly impacted. However, the *sdcX* seems to handle the additional “background” data traffic significantly better than the *SDClib/C*. Results indicate a three times shorter maximum delay and more than 8 times less data points arriving after the 50-millisecond window. In our results, the uncertainty of delay caused by the wireless transmission leads to a maximum latency in the “busy” case which is surprisingly lower than the non-busy case.

Additionally, the battery longevity of the system was experimentally evaluated. In the above setup, the WTS could be powered nonstop from a single battery charge for 27 hours and 11 minutes before shutting down.

4 Discussion

The results of this series are well in line with the results of similar projects (Berger et al., 2019; Kasparick et al., 2017; Vossel et al., 2020), consistently performing below 50 ms for at least 99.395% of data points sent. The *sdcX*-based implementation generally performs better, especially under heavy network load. This can be attributed to an improved architecture and threading model. However, the library itself provides no assurance of bounded processing delays, leading to a higher standard deviation.

As expected, WiFi is susceptible to disturbances and random delays, resulting in more deviations than the wired network achieves. This is due to the open nature of WiFi where symbol collisions are accepted in favor of a less complicated scheduling system. Since every network member has the same priority, highly critical and time-sensitive traffic is easily displaced by a concurrent low-priority data transfer. In a separate experiment, it was shown that a collision due to the connection & sign-in process of a new WiFi device could cause the data transmission to drop completely for 5-7 seconds, an outage that would be unacceptable for surgical applications.

These shortcomings may be addressed in future work by applying the advantages of a private 5G network, which assigns priorities to network connections and makes use of strict scheduling to avoid collisions.

Future developments could intend to further improve latency, jitter and reliability of wireless tracking systems by integrating SDC with other network technologies, such as *time-sensitive networking* (Rother et al., 2020). However, the application of time-sensitive networking over *wireless* channels is yet another ongoing research topic (Sachs et al., 2019), where the necessary ease of plug-and-play usability is yet out of reach.

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