Remote maintenance system for semi-automated manufacturing machines

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Abstract— **The increasing of globalization requires companies to ship their machines all over the world. This growth of exportation of manufacturing systems increased costs of maintenance due to the requirement of sending technicians to the production site where the machine is installed. The strong spread of mobile devices and the increased quality of networks opened new horizons for maintenance and support services. The work presented in this paper describes a real application case and proposes an approach for using mobile internet devices (MID) on the production site for acquisition and transmission of multi-source information that can be used from service personnel to try to resolve issues from the vendor service center.**

The purpose of this article is to present an approach to implement a remote maintenance system based on a mobile platform that allows hybrid (video and telemetry) logging.

Index Terms— **human in the loop, remote maintenance, smart factory, smartphone**

I. Introduction

The growth of the globalized market forces companies to always look for the best quality in terms of reliability of their products and support services in case of failure. Therefore, being able to provide good maintenance services is crucial to take part to this global race, see [1], [2], [3].

Producers of manufacturing machines are requested to provide warranty and often sell maintenance contracts to their customers. The intervention in case of failure or malfunctioning of the machine installed on the customer site could be really expensive and many times service personnel is moving just for issues that can be solved with simple steps if only the technician could have seen it directly. Considering that each intervention is just a cost for the company, vendors need to find a way for managing the maintenance efficiently, even when machines are far away. Additionally, if the company is able to offer rapid maintenance because it can leverage remote support techniques, it can guarantee short downtimes in case of failure. It is evident that such short times of recovery could be reached only if specialized personnel is available on the customer site, or if the technicians from the vendor site could somehow resolve the issue remotely.

Remote monitoring systems are playing a key role in this area, thanks also to the introduction of the Internet of Things [4], because they allow vendors to continuously monitor the usage and the performance of their machinery, allowing them to alert customers if some wrong behaviour is detected or a misuse by the operator is identified.

These systems somehow allow manufacturing and assembly problems on the factory floor to be solved without the on-site intervention of skilled personnel, see [5], [6], [7], [8].

Such remote monitoring systems could be enough for automated machines but they lack support for human-in-the-loop machines, which are manual or semi-automated machines, where an external input (the user operating the machine) interacts with it (see [9]). In such cases in fact it is hard to understand remotely why a certain behavior takes place during the normal functioning on the machine without seeing how the operator is using it. A malfunction can be due to the wrong usage by the operator or due to a failure of the machine under particular inputs by the operator. Considering these types of machines, the best approach is to acquire the internal data of the system together with a video that captures how the operator is interacting with the plant. Once this hybrid acquisition has been made, it can be packaged and sent over the network to the vendor support site for analysis.

Smart devices (like smartphones or tablets) provide a cost-effective solution to such requirements with their good computational power and their plenty of interfaces. They can be programmed easily, and they provide a good flexibility to support various roles.

This paper describes an innovative approach to remote maintenance specifically for semi-automated machines using smart devices as acquisition tools. The specific application that has been considered as use case is an industrial system that can be used by the operator for lifting heavy parts. This device eliminates the weight of the object to be lifted by compensating it with an equal and opposite force given by a

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motor.

The developed system allows operators of the machine to record video and internal data of the machine together for sending it to the vendor's support center.

The paper in Section 2 describes the experimental setup of the prototype, in Section 3 the synchronization problem is explained and a solution presented. Finally, Sections 4 and 5 present the real system and a final assessment of the architecture.

II. EXPERIMENTAL SETUP

The architecture has been designed to be applied on either new or legacy machines.

Figure 1 - Architecture

The architecture represented in Figure 1 is made up of three components: the machine with its own electronics, a gateway that connected to the machine bridges the data over a wireless network, the smart device that can collect data and video and sends the package to the service centre, and the vendor's factory where the support centre personnel can assess the collected data.

The real case, described in this document, fits perfectly with the general paradigm that is defined in this paper. The machine is an industrial manipulator [10] [11] actuated by operator command. This section of the paper is devoted to the detailed description of each component of the case study.

2.1 Machine architecture

The machine is composed by three electronic boards that communicate through a CAN backbone. This makes the device perfect for this application because the gateway can be installed on the CAN backbone and it is allowed to read all the data that runs inside it.

The three boards of the machine are:

- Power supply board: it manages the power supply for the machine, rectifying the voltage network to get 24 V DC for the electronic components and 65 V DC for the main motor of the machine;
- Motor control board: it manages, controls and monitors the main motor of the machine, in order to perform the optimal movement depending on the speed set-point generated by the control board. This board is also necessary to control the safety devices of the machine;
- Command board: this board implements all the algorithms to implement the HMI and controls all machine operations. In particular the main activity is to acquire from the operator the desired movements and speeds in order to generate the speed set-point.

2.2 Structure of the gateway

The gateway has a simple task: send the data collected from the CAN bus over a Wi-Fi network. The wireless network has been selected due to the wide availability on the smartphones and tablets, dropping the limitations that would have been introduced by using the Bluetooth connection that is not available on iOS devices without a MFi certification.

The selected module for the wireless connection is a Wi-Fi Roving Networks RN-131G/C, directly connected to the controller through a serial port. This module supports multiple working modes:

- Infrastructure: the module is connected to an existing Wi- Fi network;
- Ad Hoc: a point-to-point communication channel can be created (between the module and the smartphone);
- Soft-AP: the behaviour of the radio module is equivalent to an access point (with a maximum number of seven clients).

In this work, the soft-AP mode is used, to allow the machine to spread its own wireless network the mobile device can connect to.

2.3 Smart-device application

The layout of the smart device application is represented in Figure 2.

The application is Android-based written in Java: in the Android architecture each screen of the application is a so-called "activity". Figure 2 depicts the flow between the application activities with the typical workflow as follows

1. Splash screen;
2. Main screen;
3. Machine selection;
4. Machine connection;
5. Return to main screen;
6. Record;
7. Video and data acquisition;
8. Return to main screen;
9. Review / Send;
10. Log selection;
11. Review of the acquired data (both video and signals);
12. Return to the log selection screen;
13. Sending of the log;
14. Return to the log selection screen;
15. Return to main screen;
16. Exit from the app.

The remote transmission of video and operational data is currently sent via e-mail with a log attached. The app automatically disconnects from the gateway when the sending is requested to allow the smartphone to connect to another Wi-Fi connection that allows access to the Internet.

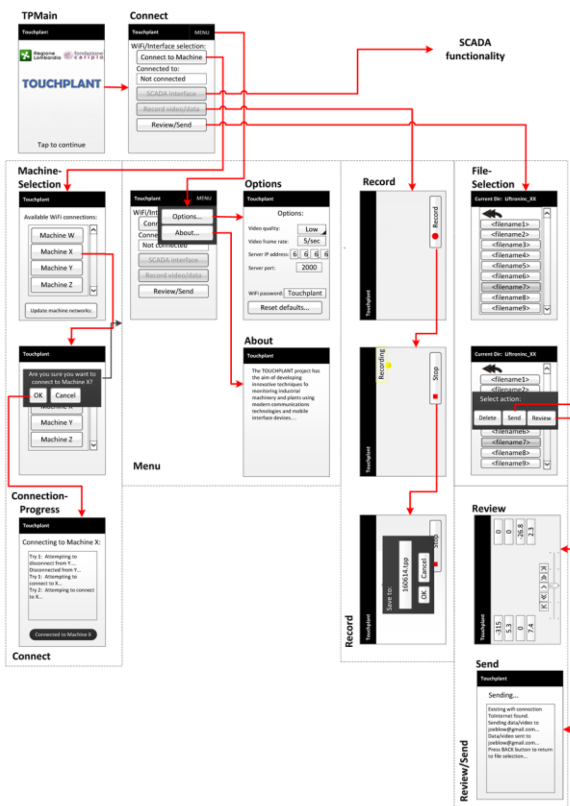

Figure 2 - Layout of the smart device application

2.4 Useful data to manage maintenance interventions

The data acquired from the machine are necessary to determine the real functioning status and, consequently, to define the maintenance interventions and how to manage these operations remotely. The logs collected can be sent to the manufacturer for further analysis by skilled personnel who will determine if the machine is in good shape or if something is not working correctly. With this purpose, the main data acquired are related to:

- Motor current;
- Motor voltage;
- Motor speeds;
- Operator commands;
- Handling times;
- General I/O;
- Alarms and warning messages.

Currents and voltages can be analyzed to see if the electrical components are functioning properly. Through these signals and the speeds, it is possible to diagnose the motor – the main actuator of the machine – to determine its condition and whether it is malfunctioning and, if so, what type of failure is present.

I/O signals and alarms can be used for understanding if the control logic is working properly and if the status of the electromechanical components is good.

The movement speed and the handling time can be used to detect problems in the motion system, especially regarding the lift cables, the system of pulleys and the grasp system.

III. SYNCHRONIZATION

One of the key points of the presented solution is the synchronization of video and machine operating data. The two streams need to be synchronized in order to be meaningful and useful for debugging issues.

The video stream is acquired with a sample rate of 30 Hz, while the rate of the signals is 10 Hz. These two streams are acquired, as previously described, with the support of:

- The digital camera of the smartphone and an audio stream from the microphone;
- A communication channel (Wi-Fi) between the terminal and the machine.

To minimize the response time between the gateway and the MID the network is a single-hop connection so that the Wi-Fi gateway and the mobile device are directly connected.

The application is developed in order to guarantee the minimum time delay between the activation of video recording and the start of data acquisition.

The architecture of the synchronization module of the app is depicted in Figure 3. When the user starts the recording the operating system is requested to enable the peripheral (the camera) and the operating system can respond in a time that depends on the availability of the resource and on other tasks running at that time. For this reason the acquisition start message is sent to the gateway only after the positive response from the peripheral request.

During the acquisition, the video and the data streams are managed by two different threads: the video manager writes an mp4 file, while the data-stream manager writes a simple ASCII file (the file layout is described in the previous section).

In order to manage the synchronization of these streams, the data file contains the information related to the elapsed time of the acquisition for each sampling cycle.

In order to evaluate the synchronization performance, it is important to define some measures (related to Figure 4)

- *TOF* (Time Of Flight) The time that is needed to send a packet from one point to another in the network (in this case a simple two-point network is created), considered constant and symmetric (this approximation was validated experimentally)
- *CT* (Computation Time) The time for the elaboration of the received packet by the gateway
- T_s (Sample Time) The time between two consecutive samples

It is easy to understand that, if *TOF* and *CT* tend to a value lower than T_s, the delay between the request and the response could be approximated to *0 ms*. In order to verify the value of *TOF* and *CT*, an experiment was performed.

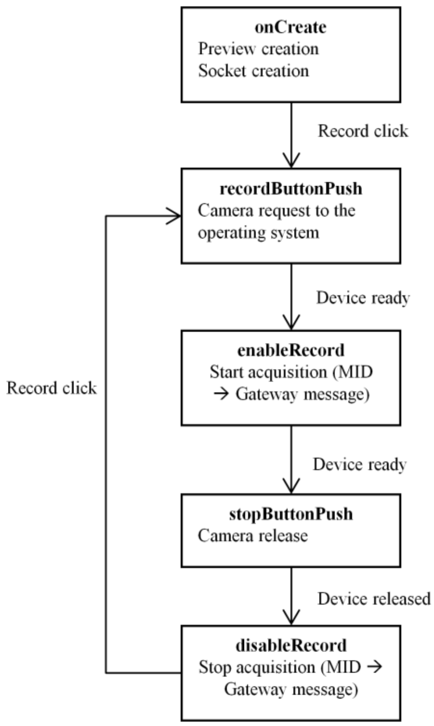

Figure 3 - Record flow chart

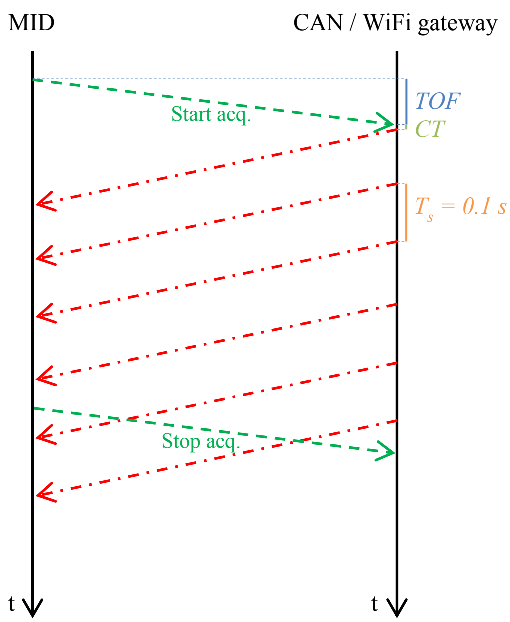

Figure 4 Transmission graph

The experiment carried out calculates the sum of TOF and CT by sending a packet from the MID to the Gateway onboard on the machine and configuring the gateway to respond to each packet with a sample packet. Executing the same operation several times and logging the timing of each operation some statistical data is derived.

The value of CT has been obtained by changing the value of a digital output during the evaluation of the algorithm and measured with external equipment. The scheme of the test is shown in Figure 5.

The results of the experiment are detailed in Table I. The mean *TOF* for a complete round-trip, compared with the standard T_s, has a very small value (approximately 9%; with the computation time <10%). For this reason it is possible to neglect the delay between sending and receiving the packet.

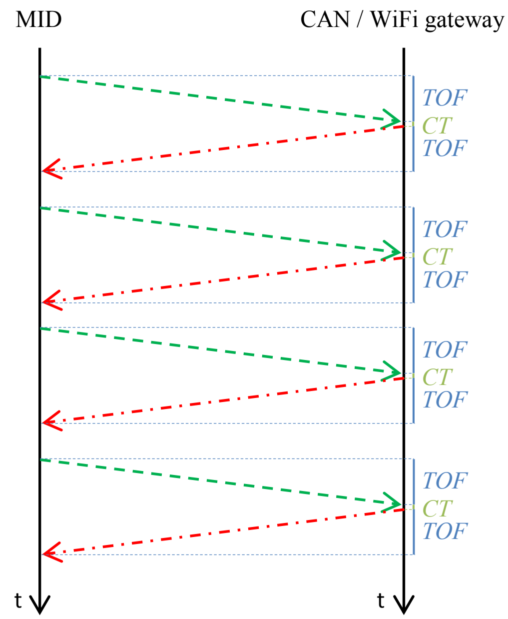

Figure 5 - Test scheme

Table I - Tests results

	Average value [ms]	Standard deviation [ms]
TOF	4.51	1.7
CT	0.73	0.012

IV. EXPERIMENTAL RESULTS

The overall system has been tested on a real plant. The steps that have been performed are the following:

- Acquisition of different complete working cycles
- Review of the acquired data on the MID
- Transmission of data to the manufacturer;
- Remote evaluation of the logs.

These tests are provided, as simple example, on the descripted case study machine; obviously, the result are extendible to different machines with a similar structure (the only requirement is the presence of the CAN backbone).

V. CONCLUSIONS AND FUTURE DEVELOPMENTS

In this paper an approach to remote maintenance for semi-automated machines is presented. The crucial point of the outlined solution is the synchronization between the gateway and the smart device.

The designed solution is based on a simple, lowcomputation synchronization protocol. The solution has been tested in a real industrial setting.

Future development will be as follows:

- Implementation of a standard "industrial" synchronization protocol in order to evaluate the performance of this system with respect to other, common solutions;
- Coexistence test of the complete system in order to verify the robustness of the solution in harsh industrial environments;
- Development of a multi-client gateway, in order to allow simultaneous communication with more than one smart device;
- Implementation of a server application for the support centre. This activity will be split into two different steps:
  - Implementation of a supervised maintenance solution (with the support of skilled technicians); The application will require a video player that allows the reproduction of the video together with the data gathered from the plant.

Implementation of an unmanned maintenance system, able to perform fault detection and isolation without the support of personnel.

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