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An application of the remote maintenance paradigm to semi-automated machines

Fabio Previdi[1], Mirko Mazzoleni[1], Alberto L. Cologni[1], Michele Ermidoro[1]

[1] Department of Management, Information and Production Engineering
Università degli Studi di Bergamo, Dalmine (BG), 24044 Italy
fabio.previdi@unibg.it

Abstract – **The increasing need of fast maintenance on machines when issues arise, and the always-increasing globalization, requires companies to find new ways for assisting customers, which can be all over the world, in a fast and economic way. It is no longer possible to send out technicians wherever a maintenance is needed because this intervention has large costs in terms of time and money. If many solutions have been proposed in the context of automated machines and plants, still some research has to be carried out in the area of semi-automated machines. In fact, the behavior of such machines could depend upon how the operator uses it. This paper presents an application of Mobile Internet Devices (MID) as a tool for remote maintenance, leveraging its connectivity and sensors for acquiring streams of data, that can be sent to the vendor service center later on to be inspected by highly qualified personnel.**

I. INTRODUCTION

Day by day, due to the ever increasing globalized market, machine producers are faced with the requirement of providing fast and in-place maintenance, see [1][2][3].

The requirement of fast maintenance in most cases could mean high costs for companies that has to send technicians overseas to fix issues that arise on manufacturing machines. In certain occurrences, the physical intervention of the technician is required to address the issue, but in the majority of the cases, the problem can be solved by a reconfiguration of the software or by simply correcting the way that the operators interact with the machine.

Other than costs, another important factor is timing: companies can have SLAs (Service Level Agreements) in place that require them to address any issue in a certain amount of time to reduce downtimes at the minimum necessary. This means that every time a problem come up a technician has to be dispatched immediately to reach the remote location where the machine is installed.

Thanks to the introduction of the Internet of Things [4], this problem has already been faced and solved with the development of remote maintenance systems that allow monitoring, assessment and remediation of most issues from the manufacturer service center [5][6][7]. These already available systems are working really well for automated machines, but there is still lack of support for semi-automated machines. These machines in fact could present issues due to a misuse by the operator. The main challenge when trying to debug remotely a semi-automated machine is understand how the operator is interacting with it and what is the environment where the machine is operating.

This paper presents an approach for the remote maintenance of a semi-automated machine [8][9]. The main idea is based on acquiring both data coming from the machine (e.g. telemetry) and a video-recording of the operator that interacts with the machine. These two streams has to be synchronized in order to ensure the perfect timing between the actions of the operator and the values of the acquired variables.

To achieve this objective, the proposed solution leverages widely available commodity hardware like the mobile internet devices (MIDs).These devices in fact are nowadays widely available and they allow to easily develop custom softtware (applications) that can run on them. These devices has various sensors (camera, microphone) and interfaces (Wi-Fi, Bluetooth, NFC) that can be used to acquire data and transmit them to the manufacturer service centre.

The proposed solution implements a smartphone application that is able to record a video of the operator using the machine, synchronized with a data stream coming from the machine itself. This can help to assess both the machine failure and a possible incorrect use that the operator made of the device.

The paper is organized as follows: Section II describes the architecture of the remote maintenance system, Section III focuses on how the synchronization of the two streams is achieved, Section IV presents an evaluation of performances to validate the robustness of the solution and Section V is devoted to conclusions and future developments.

II. SYSTEM ARCHITECTURE

The architecture of the proposed system, shown in Fig. 1, has been designed with the purpose of being applied to both new and legacy hardware. Thus it doesn't rely on the hardware having modern connection interfaces, but it relies on a ad-hoc gateway specifically built for each machine this system has to be applied to.

«Machine» with own electronic (in customer site)   Wired / Wireless gateway   User MID   Machine Manufacturer and/or service center and/or distributor and/or maintainer

Fig. 1. The system architecture

The architecture is then composed by three parts:

- Ad-hoc gateway – To be connected to the machine via an available interface. Its task is to basically acquire the data stream from the machine and route it over a Wi-Fi network for acquisition by the MID.

- MID – The MID is the central component of this architecture. It is used for acquiring the data stream coming from the gateway, together with a video recording of the operator interacting with the machine. This two pieces of information are then packed together and sent over the Internet to the manufacturer service centre.

- Vendor service center – The support center where the information acquired on the production site is routed. Here, trained service personnel assess the data received and provides solutions to the problem remotely. It the issue is not solvable remotely, then a technician is dispatched.

A. Gateway

The main task to be accomplished by the gateway is to send the stream of data over a wireless network. Without taking into consideration the interface of the gateway towards the machine (which may vary depending on the machine it has to communicate with) the main connection module that the gateway features is a Wi-Fi connection module. This network has been selected due to its wide availability on MID, and for allowing the support to iOS devices that would have required a MFi certification if the selected connection were Bluetooth.

The selected module for the gateway is a Wi-Fi Roving Networks RN-131G/C, connected to the micro controller through a serial port. As many Wi-Fi modules, this one supports the following operative modes: (i) infrastructure, where the module has to be connected to an existing network, (ii) Ad-hoc, which enables the module to set up a point-to-point channel and (iii) Soft-AP which makes the module operate as an access point with a maximum number of seven clients connected simultaneously.

The selected operating mode for the gateway is the Soft-AP mode, to allow each machine to generate its own network. In this way, the operator with the MID is presented with a list of all the available networks generated by each machine and he can select which one he wants to connect to.

B. MID application

The application that runs on the MID is Android based and thus written in the Java programming language. The application is based on 15 views that guide the user through the process of acquiring data, reviewing and sending.
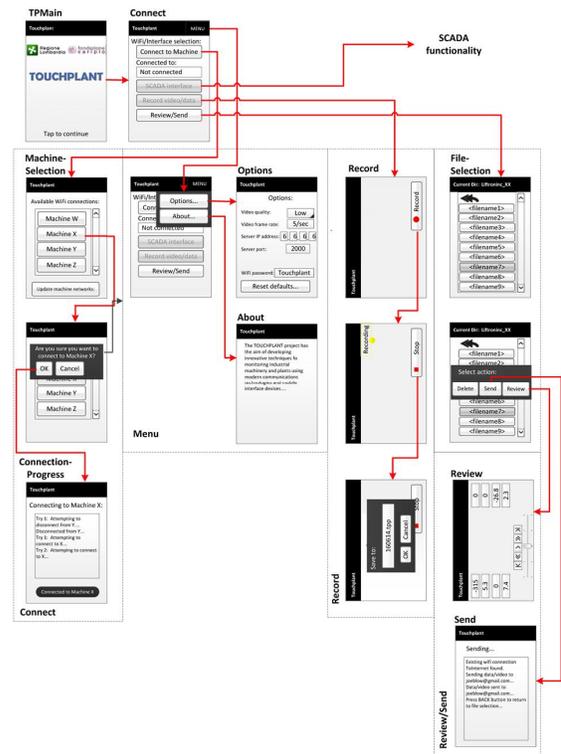

Fig. 2. The app structure

Fig. 2 represents the various views of the application. When the user initially opens the application, a list of the available machines is presented. The operator can then decide which machine he wants to connect to by tapping

on the relative name.

After that the connection has been established, the app is ready for acquiring a recording of the operator using the machine. As soon as the recording button is pressed, the app sends a "start" signal to the gateway, which will begin sending data. The app acquires both data from the gateway and video from the camera and puts them together in a synchronized package. When the recording button is pressed for stopping the acquisition, the app sends a "stop" signal to the gateway, which will stop sending data. The package is now acquired and ready to be sent. The user can choose to review the package before sending it. In that case, the video is played with the values of the recorded variables running on the screen.

Once the user is satisfied with the acquisition, he can send the package to the service center from the app. The package is sent over with an e-mail message. To allow the device to send the e-mail message, the app disconnects the MID from the machine network and connects to the default wireless network of the production site, gaining an access to the Internet.

C. Communication protocol

The communication between the gateway and the MID is a basic ASCII serial communication. A very simple protocol has been created for the purpose of starting and stopping the transmission of data from the gateway.

The protocol defined accepts the following two commands:

- **GO** – Tells the gateway to start the transmission of data

- **STOP** – Tells the gateway to stop the transmission of data

III. SYNCHRONIZATION

Synchronization in this specific application plays an important role. If the video and the data stream are not synchronized, the remote assessment can be hard or not possible at all. It is in fact critical to see which values variables had in the exact moment when the operator was operating the machine to be able to debug machine issues. Video and machine data streams are acquired, as stated before, by means of the MID camera and microphone, and a Wi-Fi connection, respectively.

The purpose of having the gateway configured in Soft-AP mode is to have a single-hop connection between the gateway and the smartphone. In such way, the latency between the two is minimum and it is enough to keep the two stream in sync; section IV will provide evidence of the tests made.

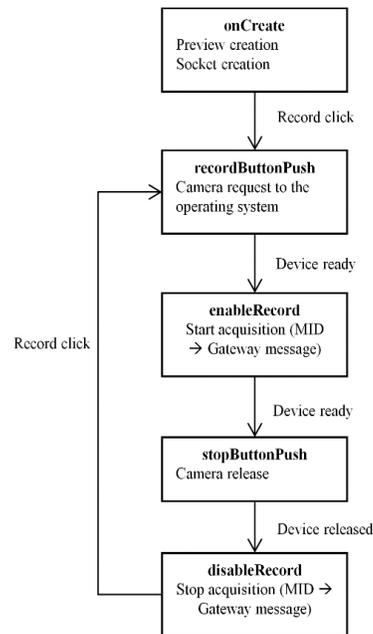When considering synchronization, it has to be

Fig. 3. Synchronization module layout

considered that application runs with an operating system underneath, meaning that access to resources such as the video camera could be delayed because for example the device can be busy, or can take some time to be initialized. For this reason, the application implements the following pattern when requested to start a recording:

1. A socket with the gateway is opened and a connection established

2. The camera access is requested to the operating system

3. The OS grants the access to the camera, notifying the application that the device is ready

4. Only at this point the GO message is sent to the gateway, and the acquisition of the video is started

The sequence of the operations is relevant: swapping steps 2 and 3 can cause several delays in the recording to be started, with the consequence of having an out-of-sync stream. The layout of the synchronization process is depicted in Fig. 3.

Two different threads acquire the two streams of data. The video stream, acquired at 30Hz, is stored in an mp4 file, while variables coming from the gateway at 10Hz are stored in an ASCII file. Both streams are timestamped since the starting point, to allow a perfect realignment if I/O operations or other applications running on the device cause one stream to be delayed.

IV. EVALUATION OF PERFORMANCES

This section describes the test carried out in order to evaluate and validate the synchronization between the two streams of data.

Prior to dive into the description of the test, some measures have to be defined:

- TOF: Time of Flight, the time needed for a single packet to travel from one end to the other one.
- PT: Processing time, the time needed for the processing of the received packet by the gateway.
- T: Sample time, time that passes between two sequential samples (period of sampling)

The empirical test carried out wants to prove that the sum of TOF and PT are much lower than T, meaning that the stream transmission is not delayed.

The challenge is then to measure the TOF and PT.

For this purpose, a custom version of the gateway software has been installed to reply with a predefined payload to each packet sent by the mobile device. In this way, the smartphone can measure the entire round trip time (the time passed since it has sent the packet and the received response).

The measuring of the PT time has been obtained pulling up a digital output on the gateway board and monitoring it with external equipment. Fig. 4 explains the structure of the experiment.
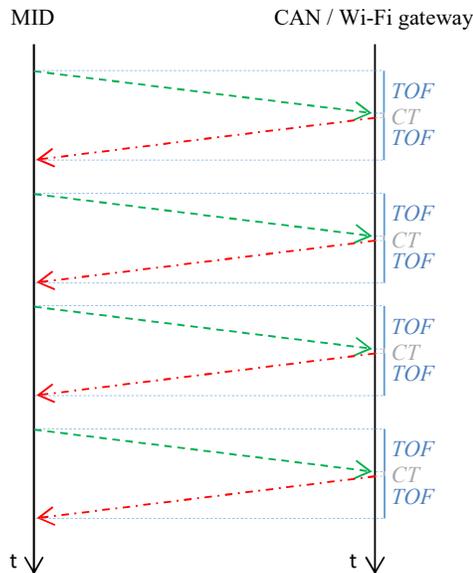

Fig. 4. Measuring of TOF and CT

Table 1 reports the experimental results achieved. The round trip time compared to the sampling time is very small (less than 10%) meaning that a lot of slack is available after having received the packet, before the next sampling.

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

Table 1. Experimental results

V. CONCLUSIONS

This article presented an approach to remote maintenance using mobile internet devices. The critical part of this application is the synchronization between the two stream which has been addressed and tested in an empirical way. Future developments will be the implementation of a bidirectional communication that will allow the service centre to update the configuration of the machine remotely for debugging purposes.

VI. AKNOWLEDGMENT

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