Knowledge Capture inside a Haptic Soldering Environment

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Abstract

In the electronics manufacturing industry, soldering plays a key role in the process, whether it is carried out manually, semi-automatically or fully automatically. Even though the basic techniques in manual soldering are comparatively straightforward, to master it at a high level still requires a lot of time and effort. The research presented in this paper aims to identify the motor skills involved in soldering and the ability to recognise when a soldering process is likely to go wrong. If this soldering knowledge was able to be captured, this would allow the development of automated soldering processes that work more efficiently. By simulating the manual soldering process in a haptics environment, the aim is to employ automated user logging to investigate human hand dexterity and learn how novices and experts operate differently. A pilot study was conducted to compare users carrying out a basic soldering task in real-life and in the haptic environment. By automated parsing of the logfiles obtained from the soldering sessions, important user actions were extracted and formalised using several knowledge representations. Future work will involve developing a more sophisticated haptics environment and to conduct a more intensive user trial involving more users.

Keywords: Haptic simulation, soldering, knowledge capture.

1. Introduction

The advent of surface-mount technology (SMT) coupled with industries' need for productivity and reliability has spawned the development of automated soldering machines. Selective soldering machines have since been developed however, no matter how technology evolves or how small components become, the decades-old hand soldering process remains.

Since the automation of the soldering process is still expensive and often inflexible, it has caused manual soldering to still be common even in high labour costs economies, particularly in low and medium volume production environments, so hand soldering is an essential process in PCB assembly and rework. However, based on feedback from industry, adaptations in equipment and techniques are needed to meet the temperature concerns of today's packages and remove any variability in the soldering process. Soldering is also a skill that must be taught correctly and developed with practice. However, if the skills involved were able to be identified more precisely, this would allow the teaching of the process to be more effective as well as aiding in the development of more efficient automated soldering processes.

In the presented research, a haptic device has been used to simulate a soldering environment, and by logging the movement of the haptic pen, the forces, velocities and motion of the user's hand can be obtained. By parsing the resultant log files, important steps performed by the user are extracted and formalised using several knowledge representation formats used in previous research (Sung et al, 2009). Through the analysis of the experimental data, the aim is to identify what is required to achieve a good soldering process.

An overview of the research in haptics and hand tremors is presented in section 2 while the haptic soldering environment is detailed in section 3. Next, details of a pilot study are presented in section 4 while the results are shown in section 5. Finally, a discussion of the results is given in section 6 and the paper ends with some conclusions.

2. Overview of Haptics & Hand Dexterity Research

This section will give an overview of the varied research involving haptics as well as the study of hand tremors – an important characteristic which has a significant effect on the quality of manual soldering process.

2.1. Haptics Research

Since the appearance of haptic devices, there has been widespread research involving the use of the technology to simulate real-world applications and to study hand motion. In one study (Broeren et al, 2007), 58 healthy subjects were required to use a haptic device to move a cursor towards several targets on a screen. The aims of the study was to investigate whether repeating the test with each subject would have any training effect, and also whether it was possible to generate the 3D trajectories of the users' hand motions. The results showed that there was good test-retest reliability, and the users' performance did improve when comparing the first and third session results of each user.

Next, a system was proposed which enabled a user to tele-operate a robot to perform the assembly of micro components (Estevez et al, 2010). A benchmark application has been created to assess the requirements of the final micro-assembly haptic system, and a micro-drive is used as the test assembly during the analysis. From the results of the analysis, it was found that most of the assembly operations involved aligning components with a vertical axis and also performing peg-in-hole operations. The system is still being designed and built so no results exist.

In another paper, a system called HAMMS (Haptic Assembly, Manufacturing and Machining System) is detailed (Lim et al, 2009). Experiments were carried out in which participants had to assemble a pump assembly in the real world and in the haptic environment and the results were compared. As well as analysis of the assembly times, the motion of the haptic pen was also studied to determine if it can be used as a gauge of how confident the user was. The experimental results showed that the haptic assembly times were generally longer than those in the real world - due to factors like haptic damping – but there were similarities in both cases when considering the overall trend of the assembly times; one example of this was that in both cases the same component took the longest time to assemble.

In the research field of virtual welding environments, a lot of work is done in this area. Whereas some systems rely on having the user operate a real welding torch that is either attached to a force feedback device (Fast et al¸2004) or is motion tracked (White et al, 2009), other systems make use of an off-the-shelf haptic device (Wang et al, 2006; Wang et al, 2009]. Furthermore, there is also research carried out on algorithms that are used to display realistic-looking weld beads (Jo et al, 2009), which is relevant to the research presented in this paper if the realistic rendering of solder flow is required.

From the review of the literature, a diverse range of research involving haptics was witnessed but there is a noticeable lack of work in the area of soldering. One system was found which used a graphics tablet instead of a haptic device to simulate the soldering process (Venkittarayan et al, 2010). The user operates the system using a stylus and the quality of the soldering can be varied by adjusting the pressure and tilt of the stylus. From the results of the user study, the feedback was encouraging but users with soldering experience found the system lacked realism compared with the real-world process. At present, the system only utilises one stylus, whereas the system presented in this paper uses dual haptic devices. Furthermore, the use of a graphics tablet means that the force feedback will be fixed in one plane – a problem not encountered with a haptic device.

Due to the small amount of research in the area of virtual soldering environments, the research presented in this paper is warranted, and based on the various successful virtual training environments in other areas such as welding, a virtual soldering system could potentially bring many important time and cost benefits.

3. Haptic Soldering Environment

The haptic soldering environment consists of two Sensable Phantom Omni™ devices (Figure 1) that run the software environment developed using the OpenHaptics API.

The standard configuration has the right-hand side Phantom Omni controlling the soldering iron and the left-hand side controlling the tweezer that is used to position the resistor that is to be soldered, as shown in Figure 2. Depressing a button on the left-hand side controller also displays the soldering wire so solder can be applied onto the soldering iron. The 3D model of the soldering iron was created in Siemens NX™ while the model of the printed circuit board was obtained from the Opal Kelly site (Opal, 2011). To use as a benchmark for the haptics environment, the user trial also involved performing a real-world soldering task that required each user to solder a resistor to a PCB, as shown in Figure 2.

Figure 1 - **Two Phantom Omni Haptic Devices**

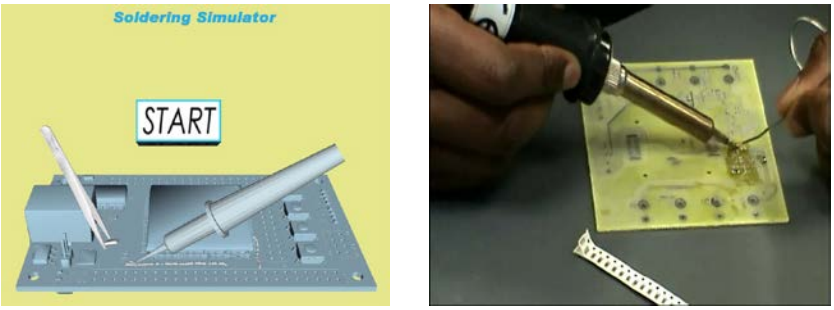


Figure 2 – **Virtual (left) and Real-World (right) Soldering Environment**

4. Experimental Methodology

The pilot study involved two users with prior soldering experience carrying out a soldering task in real world and in the haptic environment. Both users were male and right-handed. User activity in the haptic environment is automatically and unobtrusively logged in the background so properties such as the force, velocity, position and angle of the haptic pen is recorded, as well as the haptic pen buttons that are pressed. Furthermore, a timestamp in milliseconds is associated with each logged action.

In the real world case, the user has to solder a resistor onto a PCB, while in the haptic environment the user has to replicate the action of the soldering process. After each user had completed both tasks, a questionnaire was filled-in, the purpose of which was to find out the following information from the participant:

- Their demographic characteristics;
- Their soldering experience;
- What they liked and disliked about using the haptic device;

- What they liked and disliked about the virtual soldering environment;
- Give comments on what improvements they would like to see in a future revision of the virtual soldering environment.

By automated parsing of the log files obtained from the haptic session using a spreadsheet macro, important user actions were extracted and formalised using several knowledge representations used in previous research (Sung et al, 2009). The representations used are:

- XML (Extensible Markup Language) (EML, 2011);
- PSL (Process Specification Language) (Gruninger and Bock, 2005);
- IDEF0 (Integrated Definition Methods) diagrams (IDM, 2011);
- DRed (Design Rationale Editor) (Kim et al, 2004;
- English-syntax instructions.

Both XML and PSL are codified representations that are used in industry (Sung et al, 2009], which means prior knowledge is required to be able to understand the representations. Unlike XML and PSL, IDEF0 diagrams and DRed graphs give a more visual representation so the processes that occurred during a soldering session can be seen at a glance. Figure 3 shows the components that make up an IDEF0 diagram but the “Call” component will not be required in this research.

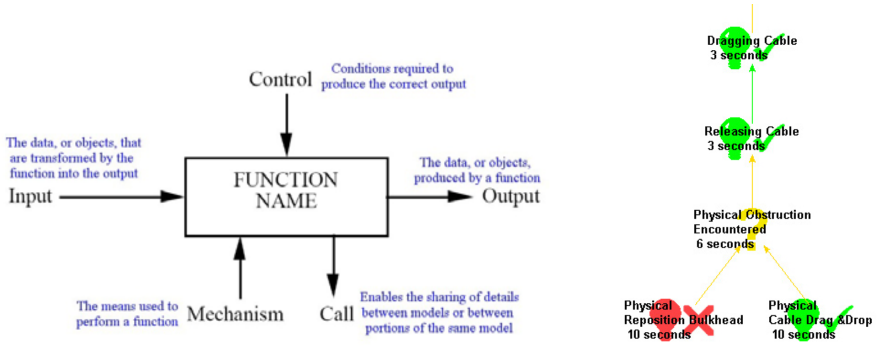


Figure 3 – **Examples of an IDEF0 Diagram (left) and DRed Graph (right)**

DRed graphs were developed to record decisions that were made during a meeting and the graphs are traditionally manually constructed as a meeting progresses. One key benefit of DRed graphs is that as well as showing correct solutions, rejected solutions are also shown, which are indicated by a red light bulb icon next to a cross, as shown in Figure 3. This means that there is a record of any mistakes that are made so new users studying the graph can learn not to perform the same errors in the future.

In addition, the arrows connecting each node in the graph are colour-coded depending on how long the user has taken to complete a task. For example, if a task is completed quickly, the arrow is green, but if it has taken a long time, the arrow is red, which may indicate a part of the soldering process where the user is experiencing difficulty.

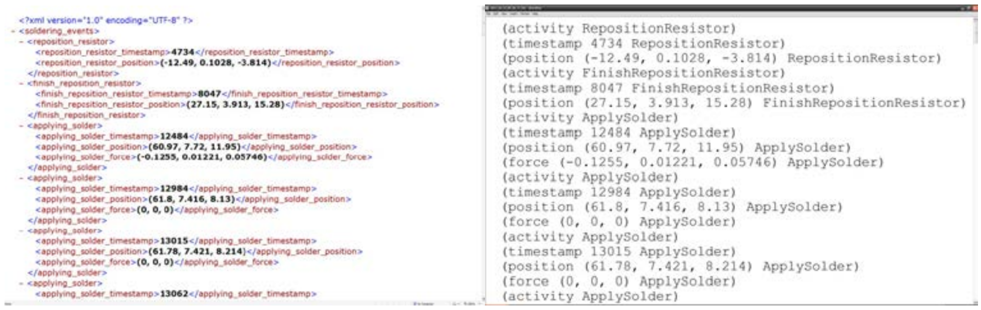
Finally, English-syntax instructions are another knowledge representation that is automatically output from the parsed log files to produce a document which can be easily-understood and can be used as a training aid for novice users.

5. Results

This section will present various knowledge representations that have been automatically generated from the automated parsing of the log files.

5.1. Knowledge Representations

From the automated parsing of the log files, the following knowledge representations were obtained:



```
<?xml version="1.0" encoding="UTF-8" ?>
- <soldering_events>
  - <reposition_resistor>
      <reposition_resistor_timestamp>4734</reposition_resistor_timestamp>
      <reposition_resistor_position>(-12.49, 0.1028, -3.814)</reposition_resistor_position>
    </reposition_resistor>
  - <finish_reposition_resistor>
      <finish_reposition_resistor_timestamp>8047</finish_reposition_resistor_timestamp>
      <finish_reposition_resistor_position>(27.15, 3.913, 15.28)</finish_reposition_resistor_position>
    </finish_reposition_resistor>
  - <applying_solder>
      <applying_solder_timestamp>12484</applying_solder_timestamp>
      <applying_solder_position>(60.97, 7.72, 11.95)</applying_solder_position>
      <applying_solder_force>(-0.1255, 0.01221, 0.05746)</applying_solder_force>
    </applying_solder>
  - <applying_solder>
      <applying_solder_timestamp>12984</applying_solder_timestamp>
      <applying_solder_position>(61.8, 7.416, 8.13)</applying_solder_position>
      <applying_solder_force>(0, 0, 0)</applying_solder_force>
    </applying_solder>
  - <applying_solder>
      <applying_solder_timestamp>13015</applying_solder_timestamp>
      <applying_solder_position>(61.78, 7.421, 8.214)</applying_solder_position>
      <applying_solder_force>(0, 0, 0)</applying_solder_force>
    </applying_solder>
  - <applying_solder>
      <applying_solder_timestamp>13062</applying_solder_timestamp>
```

```
(activity RepositionResistor)
(timestamp 4734 RepositionResistor)
(position (-12.49, 0.1028, -3.814) RepositionResistor)
(activity FinishRepositionResistor)
(timestamp 8047 FinishRepositionResistor)
(position (27.15, 3.913, 15.28) FinishRepositionResistor)
(activity ApplySolder)
(timestamp 12484 ApplySolder)
(position (60.97, 7.72, 11.95) ApplySolder)
(force (-0.1255, 0.01221, 0.05746) ApplySolder)
(activity ApplySolder)
(timestamp 12984 ApplySolder)
(position (61.8, 7.416, 8.13) ApplySolder)
(force (0, 0, 0) ApplySolder)
(activity ApplySolder)
(timestamp 13015 ApplySolder)
(position (61.78, 7.421, 8.214) ApplySolder)
(force (0, 0, 0) ApplySolder)
(activity ApplySolder)
```

Figure 4 – **XML (left) and PSL (right) Knowledge Representation**

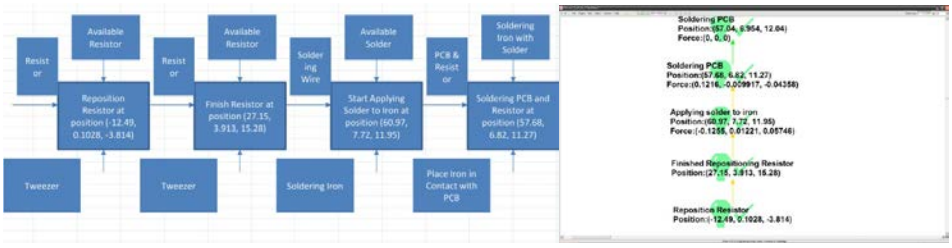
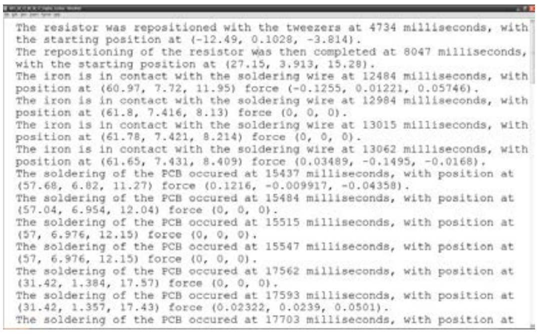


Figure 5 – **IDEF0 (left) and DRed (right) Knowledge Representation**



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The resistor was repositioned with the tweezers at 4734 milliseconds, with
the starting position at (-12.49, 0.1028, -3.814).
The repositioning of the resistor was then completed at 8047 milliseconds,
with the starting position at (27.15, 3.913, 15.28).
The iron is in contact with the soldering wire at 12484 milliseconds, with
position at (60.97, 7.72, 11.95) force (-0.1255, 0.01221, 0.05746).
The iron is in contact with the soldering wire at 12984 milliseconds, with
position at (61.8, 7.416, 8.13) force (0, 0, 0).
The iron is in contact with the soldering wire at 13015 milliseconds, with
position at (61.78, 7.421, 8.214) force (0, 0, 0).
The iron is in contact with the soldering wire at 13062 milliseconds, with
position at (61.65, 7.431, 8.409) force (0.03489, -0.1495, -0.0168).
The soldering of the PCB occured at 15437 milliseconds, with position at
(57.68, 6.82, 11.27) force (0.1216, -0.009917, -0.04358).
The soldering of the PCB occured at 15484 milliseconds, with position at
(57.04, 6.954, 12.04) force (0, 0, 0).
The soldering of the PCB occured at 15515 milliseconds, with position at
(57, 6.976, 12.15) force (0, 0, 0).
The soldering of the PCB occured at 15547 milliseconds, with position at
(57, 6.976, 12.15) force (0, 0, 0).
The soldering of the PCB occured at 17562 milliseconds, with position at
(31.42, 1.384, 17.57) force (0, 0, 0).
The soldering of the PCB occured at 17593 milliseconds, with position at
(31.42, 1.357, 17.43) force (0.02322, 0.0239, 0.0501).
The soldering of the PCB occured at 17703 milliseconds, with position at
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Figure 6 - **English Syntax Knowledge Representation**

6. Discussion

From the preliminary knowledge representations that have been automatically generated, the fundamental processes involved during a soldering session have been extracted. In addition, important characteristics like times, positions and forces have been associated with each step to allow the soldering techniques to be studied and learned by other users. From the obtained knowledge, it is envisaged that this will aid the development of more sophisticated automated soldering machines which more closely mimic the intricate soldering techniques of human soldering experts. To also allow the information in the representations to be more easily shared with other users, as a form of training aid, the data can be stored in some form of database in a company. From previous studies on various knowledge representations (Sung et al, 2009), it was discovered that users preferred representations that had a more visual aspect to them, such as storyboards and annotated video clips, so greater focus will be placed on this in future work.

Regarding task completion times between the haptic and real world environment, it was generally quicker in the haptics environment because not all the soldering tasks have been implemented in the current setup. For example, the soldering flux paste that is required to be applied during the real world task is not modelled at present but this will be added in the next revision of the environment. Another key difference is that the flow of solder is not observed on the screen so there is no visual indication of when a solder is complete.

From the questionnaire that was completed, both participants gave positive comments on the intuitiveness, tactile feedback and graphics quality on the haptic soldering environment. However, the users also commented that they would have liked shadows to aid with depth perception as well as the ability to zoom in on and rotate the PCB model, which is not possible with the current configuration. Furthermore, both users also would have liked better modelling of the solder – such as the ability for it to melt and flow – and the ability to monitor the PCB temperature and cleanliness.

Currently, it is possible to generate a 3D scatter plot in a spreadsheet of the path followed by the haptic pen during a soldering session by utilising the log files, but since an equivalent plot for the real world soldering session cannot be generated, it is not possible to compare the soldering iron motion of the two environments. One possible solution would be use some form of motion tracking system, such as an optical tracker, to follow the path of the soldering iron so this will be investigated. In addition, another aspect of the real world soldering process which is not currently measured is the forced applied by the soldering iron, which is an important characteristic to investigate in a task that requires fine motor skills. To measure the force, one method could be attached a load cell to the printed circuit board.

Other future work will involve adding a stereoscopic view to aid with the depth perception and also the ability to alter the position and orientation of the PCB. More importantly, the vertical arm movement required by the user when operating the haptic device needs to be reduced so the user can rest their wrist on a support, which then mimics better what happens in the real world. After these revisions have been completed, a more thorough user trial involving more participants – including both novice and expert users – will be carried out.

7. Conclusions

This paper has presented a pilot study in which a haptic soldering environment has been developed to investigate the skills that are required to perform successful soldering operations. By identifying these skills, it will be possible to improve the efficiency of automated soldering processes.

A pilot study was carried out which compared user activity during a real world soldering exercise and one in the haptic environment. Log files of the soldering sessions were automatically parsed to generate knowledge representations using various formats. From the representations, the key steps taken by expert users during a soldering process have been captured and future work will focus on extracting more intricate detail from the log files.

Additional future work will involve adding a stereoscopic view and allowing users to manipulate the viewpoint of the printed circuit board model.

Encouraging results have been obtained from the pilot study so further investigation is essential to fully realise the potential benefits from the virtual soldering environment.

Acknowledgments

We would like to acknowledge Renishaw PLC for their guidance throughout the project and the supply of materials for the user trials.

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