Robot based automated testing procedure dedicated to mobile devices

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Abstract–**Automated testing procedures are very useful since they can save a lot of time and human effort. However, most of them are very rigid and focused on performing very particular tasks. While this may not be a problem in case of software testing, it may prove to be a real burden when hardware testing is aimed. In many cases, this is based on dedicated industrial robots which are expensive, very difficult to move from one location to another and, in addition, require a lot of reprogramming work when changing the test scenarios. Another known problem of the existing solutions is caused by the movement of tested device. Even a small change in position can generate faulty results and, because of this, an entire test can be missed. The practical study described in this paper is represented by a robot dedicated to automated testing of mobile devices. The main differences from similar solutions derive from: size (our robot is smaller and less heavy so is portable), costs (cheaper to build and maintain), independence of display type (resistive or capacitive) and robustness (is not affected by the movement of tested device).**

***Keywords*-Image analysis; SIFT; SURF; Object recognition; Feature detection;Delta robot; Automatic testing**

I. INTRODUCTION

Continuous improvements of energy storing solutions along with the new generations of embedded systems offer now the possibility of running various software applications on mobile devices for longer periods of time. Even more, studies show that users usually work faster when using a touch screen device than when they are using a traditional PC or laptop and a mouse.

Present days, almost all mobile devices use tactile displays, either resistive or capacitive, in order to offer a simple, friendly and intuitive interface with the user. Regardless of their destination the devices which are based on tactile displays must be thoroughly tested before being launched on the market.

In what concerns the mobile devices such as phones or tablets, several testing software applications such as Appium or Selenium can be used for checking specific functionalities of the application that runs on the phone or tablet. However, they cannot simulate the gestures that a human being can perform: touch (or tap), sliding, zooming in or zooming out, rotation and so on.

Under these circumstances the best suited approach for automatic testing seems to be the one based on a robot. In this case, the machine must be able to monitor the entire screen of the mobile device, do all the necessary image processing andperform all the physical actions that a human user would perform when interacting with a mobile device.

There are very few known solutions for afore mentioned problem but each solution is capable of performing a limited number of tests [8]. So far there is no known solution capable to integrate image processing with solutions of touching the displays in multiple places (coordinates). Another problem is generated by the fact that existent top solutions are based on industrial robots that cost very much and are very hard to move from one location to another.

In this paper, a solution for automatic testing of mobile devices is presented. Ourapproach is based on a delta robot capable of analyzing mobile devices' displays based on image recognition algorithms.Various image recognition algorithms were tested and comparative results will be presented. User's actions are simulated with the aid of roboticeffectors. The paper is organized as follows: section II presents similar work; in section III the actual case study is presented; section IV is dedicated to results and discussions while the conclusions are drawn in section V.

II. RELATED WORK

During the past several years, the tactile displays have seen an unprecedented popularity and demand [1]. The support received from the R&D made possible the integration and use of such devices in various fields like: automotive industry, telecommunications, medicine, entertainment and many others. However, this wide adoption of touch screensraises a serious problem when it comes to testing these devices. The process is very exhaustive, time consuming and very difficult to implement in an automatic manner. In addition, the differences between capacitive and resistive touch screens represent, themselves, a serious challenge when it comes to designing devices that can test both types. Some attempts to develop testing robots for mobile devices will be further presented.

Most of existing automated testing solutions based on robots or robotic arms are dedicated to identification of hardware defects that may affect touch screens. This is the case ofTakTouch 1000 [6], SR-SCARA-Pro [7]etc. In most cases, the robots do not have a direct feedback from their actions through a video camera but use applications installed on the tested device [ref net5] for evaluating their work. In other cases, robots movement is based on previous data collected from human users. In other words, if a certain object must be tapped the robot needs to know the exact coordinates of that

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object. This solution is very sensitive to small movements of the mobile device or if the object is repositioned during the test.

The biggest company involved in the development of testing robots is Optofidelity [2]. Optofidelity is focused on using industrial robots and robotic arms for automatic testing procedures. However, the robots are extremely specialized; they can perform only one specific test. Under these circumstances, if several parameters must be tested, the mobile device must be moved to another robot and a new testing procedure is followed. This approach is very expensive, inefficient and time consuming. After starting a global co-operation with Symbio [4] back in 2015, Optofidelity released *OptoFidelity Human Simulator* that was integrated in Symbio's Robot Aided Test Automation framework (RATA).

In reference [9] the authorspresent a robot that follows instructions received as text messages on a display monitored by a webcam. The approach is solely based on OCRtechniques; the robot does not perform other object recognition or image analysis. After decoding each component of the command text, the robot taps it on the touch screen of a smartphone. For identifying the virtual keyboard, 2 additional webcams are used. The proposed solution is not appropriate for automated testing since it does not use any input from the smartphone and, also, is device dependent. In addition to different types of virtual keyboard layout, every smartphone manufacturer hasits own preferred font style. Moreover, this solution also has problems if the smartphone is accidentally moved.

The founder of Appium and Selenium,Jason Huggins, proposed a limited functionality robot for testing mobile applications on smartphones. Project Tapster[5] delivered a 3D printable robot that could test only smartphones with capacitive touch screens of limited size. In addition, the image analysis for object detection and recognition is almost missing.

III. CASE STUDY

As previously mentioned, our study reveals the steps of building a relatively small size robot dedicated to automated analysis of mobile devices based on image analysis and object recognition. In this section, the theoretical basis and some implementations details will be presented.

A. Image Analysis

As previously mentioned, our study resulted in a small size robot dedicated to automated analysis of mobile devices based on image analysis and object recognition. One important requirement was that the robot should be able to detect icons or areas of interest, regardless of their position or orientation. This requirement is based in human approach to identify a certain application by identifying the application's specific icon. The icons can appear anywhere on the display of a smartphone or other mobile device. Different screen is also a possibility. This is why the icons' detection system must be robust to various changes and identify the icon and its position at all times.

For these purposes, the algorithm must be:

• scale invariant

• rotation invariant

•illumination invariant

•resistant to all kinds of noise (for instance, the device can be changed but the icons should still be identified correctly)

• Good enough to observe the absence of an icon from the current tested screen

• fast enough to provide "real time like" behavior

The literature contains many studies dedicated to analyzing the performance of various image analysis algorithms for feature detection and feature description [12]. However, giving our objectives and demands mentioned above, only two algorithms were selected for thorough investigation and possible implementation on the robot. These algorithms are SURF (*Speeded up Robust Features*) and SIFT (*Scale-Invariant Feature Transform*). Both SURF and SIFT should generate robust points of interest and a scale, rotation and illumination free local descriptor. Details about SURF and SIFT can be consulted in [11][15][16][17].

SURF vs. SIFT

There are a lot of studies which tried to determine which one of SURF and SIFT performs better in various real working scenarios. Unfortunately, the results are far from being similar or they are almost contradictory [15][16][17] being highly application and hardware dependent. Based on this observation, we decided to run several comparative tests in order to determine the best algorithm for our specific problem. Since the two algorithms are based on similar principles and steps it was expected to obtain similar results when comparing them in the same conditions.

During the tests,SURF and SIFT had to detect the icons from the mobile device display. For this purpose, a testing platform (Figure 1) was designed and built.

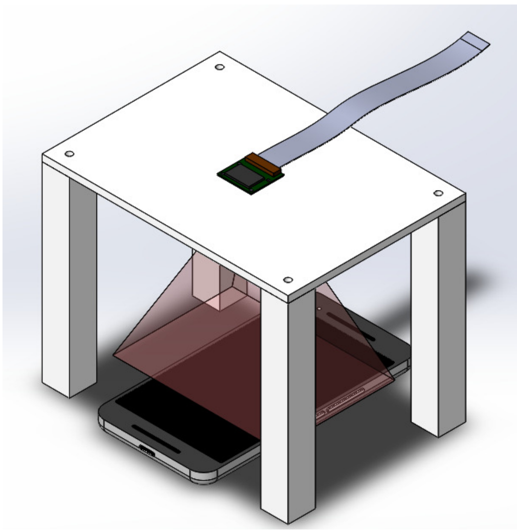

Figure 1. Testing platform

The platform presented in Figure 1 allows fast and easy replacement of target device and, most important, maintains

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constant testing conditions. SURF and SIFT were both tested against three different devices: Nexus 6p, Nexus Tab 8 and Cubot x17. Most important differences between these devices were: display type, size of the icons and colors. The displays of the mobile devices were captured with a video camera, the acquireimages being the inputs for SURF and SIFT.

At first, the icon detection was attempted by providing a very good quality icon reference in PNG format. Various image resolutions and sizes were tested but both SURF and SIFT had difficulties in finding points of interests that could be further correctly matched. It was concluded that camera's intrinsic parameters have some effect over the captured image that prevents SURF and SIFT to correctly identify the points of interest. To overcome this inconvenient, a different approach was tried. By using the same camera, a high quality and high resolution image of the tested display was acquired. From that image, each individual icon was cropped and provided to SURF and SIFT as reference. Same icons were used for all 3 tested devices.

Both SURF and SIFT generate not only True Positive but also False-Positive matched points of interest. In order to have an objective indicator for each algorithm's performance, an average precision metric was calculated for 16 icons available on each one of three tested devices. The precision is defined as a ratio between True Positive matched points and total number of generated points. The results are presented in Table I.

TABLE I. PRECISION OF SURF AND SIFT

Device	SURF	SIFT
Nexus 6p	77.59%	24.31%
Nexus Tab 8	69.01%	12.32%
Cubot x17	71.40%	19.08%

Although SURF exhibits far better average aggregated precision than SIFT (72.66% vs. 18.57%) it can also generate many False Positive matches. In Figure 2 a situation like this is presented. One can observe both the correct match and the wrong one. However, giving the huge difference between actual results obtained with SURF and SIFT, it was decided that SURF will be used for the implementation on the testing robot.

The results of SURF were further improved by using a procedure that helped eliminating False Positive points and finding the center of the icon. In the first step, a scale is computed. The scale represents the ratio of the distances between all the matched interest points in camera image and in the reference image. The distance is calculated using (1).

(1)

In the second step, after the scale is obtained for every matched interest point, a circle is drawn around it and every other interest point inside the circle is counted. The interest point with the highest number of neighbors is picked. In this way the points are counted and False-Positive points are indentified.

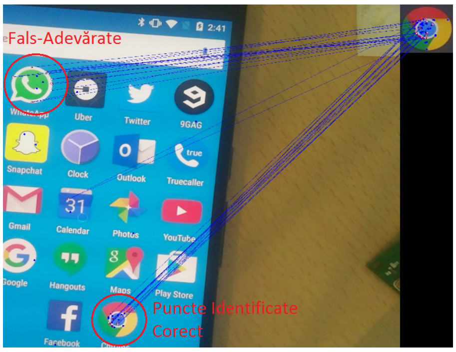

Figure 2. False Positive by SURF

B. Building the robot

Delta robots are very different from Cartesian, SCARA or serial link robots. These robots have the actuators incorporated in their arms which make them appropriate when it comes to moving heavy weights but not very good when it comes to making fast, very precise and high acceleration moves. For this kind of applications, delta robots [18] are preferred. In their case, the actuators are integrated into the central structure, above or below the working area. The robotic arms are connected to a piece named *effecter* which has one or more drive devices.

The first delta robot was proposed in 1985 by prof. Reymond Clavel from École Polytechnique Fédérale de Lausanne (EPFL)[13]. Since then, several delta type robots were proposed: horizontal linear delta robot, cube delta robot, Keops delta robot, Ibis delta robot, vertical linear delta robot and many others.

The automated testing robot presented in this paper is based on the vertical linear delta robot to which several improvements were brought. The final version of the robot is presented in Figure 3.

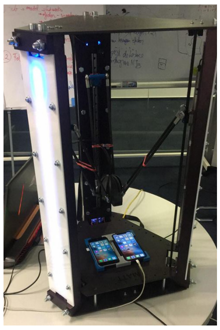

Figure 3. Final version of automated testing robot

The robot's arms are made out of carbon fiber and are connected to gliders and effecter by universal joints. The entire platform is supported by three pillars which also host the gliders. Regardless the position or speed, the effecter must be parallel with the base at all times. All the elements that will interact with a certain object within robot's perimeter (such as, for example, a tested mobile device) will be mounted on the effecter. Here are included the video camera and the "fingers" (stylus). The robot places the effecter on top of the tested object and the effecter will supply video information and also willact on the target through the drive devices.

The design of the robot was made using Solidworks[14]. This way, the behavior of different components was carefully studied so the risk of failure was dramatically reduced. Based on the simulations, the decision to use Dural for the robot's chassis was made.

One of the most important parts of the robot is represented by the effecter. Based on the visual information received from the camera and the robotic fingers, the effecter is the part of the robot that must replicate as well as possible the human behavior when interacting with a touch screen device.The actions performed by the drive devices are: zoom in, zoom out, tap, glide, move and rotate. The effecter(presented in Figure 4) has a video camera (8 MP, Sony IMX219 sensor) based on which the robot can detect points of interest like icons, characters, text fields or text boxes.

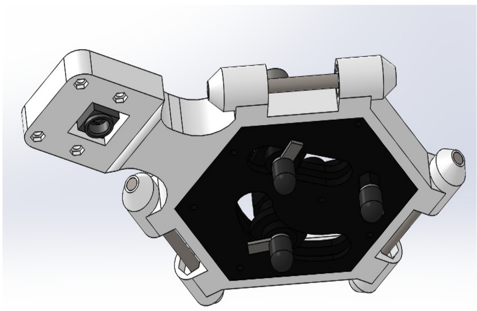

Figure 4. Robot's effecter

Another very important part of the effecter is represented by the moving parts. The stylus pens are capable to work both on resistive and capacitive touch screens. There are three pens, two mobile and one fixed. The up and down movement is controlled by two step by step motor. One of the pens can be moved forward and backward to stimulate gestures like zoom and glide while the other can realize circular movements so it can implement rotations.

The pressure applied by the stylus over the touch screen display is very important since it can either lead to the display deterioration or lack of efficiency when taping it. To prevent all possible problems, a step by step micro motor is used. The side view of the effecter is presented in Figure 5, where the three pens are easily observable.

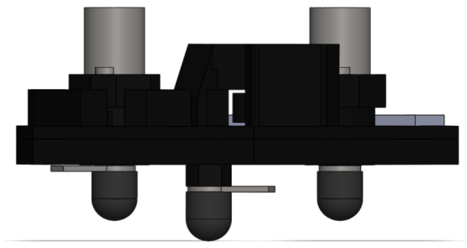

Figure 5. Side view of the effecter

C. Robot controland operation

There are many types of 3D printers based on a vertical linear delta robot. This has led to the development of many efficient control modules. Although there are many known solutions on the market, due to the specific demands of our robot, a dedicated board for control and operation was designed and implemented.

The robot incorporates 7 motors. Three of them are step by step motors used for moving the robot's arms on vertical axis. The other four motors are incorporated into the effecter for implementing the movements/gestures mentioned previously. These are highly precision micro-motorsusually used for optical stabilization of photo camera objectives.

The movement of the robot and its parts (effecter, stylus) is managed by two microcontrollers, one from STMicroelectronics and the other from Atmel. The two microcontrollers are wire-connected and they communicate through I^2C. The main board was built around STM32F103CBT6, ARM Cortex M3microcontroller running at 72 MHzthe motors are managed by the motor driver A4988 from Pololu. The command and control board was designed so it allows simple replacement of a motor driver (plug out – plug in).

D. Robot testing and results

The robot was intensively tested in various conditions using all three devices mentioned before. It was noticed that results were constant, icons being correctly identified, regardless the device and their position on the screen. Moreover, when the icon is not found in the current screen, the robot identifies this situation and searches for the icon by gliding to the next screen.

After the first version, the robot suffered continuous improvements and the actual version can be seen at [11]. The current version of the robot can type about 80 characters/min. The longest test that the robot performed lasted 48-h, in which time the robot performed a stress test on an Android application. Every time when the robot moves one mm, multiple floating-point calculations are done. Using Inverse Kinematics, the robot keeps track of the current position using the previous one. Because every floating point operation is done with a certain precision every 2 h, the robot stops and recalibrates itself.

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IV. CONCLUSIONS

In this paper, the construction of a delta robot dedicated to automated testing of mobile devices was presented. For the video feedback received from the tested devices, two of the best algorithms for detecting and identifying points of interest within an image were tested. The comparison between the algorithms was performed by using predefined icons and it aimed to reveal which is the best algorithm for this application. For high relevance and objectivity, the algorithms were tested against three different devices with different display types.

The best behaving algorithm in our test was SURF which, along with a fine tuning algorithm developed for this study, was able to eliminate most of the false positive identifications and to determine the correct position of the icon towards which the effecter will move and tap.

The robot was intensively tested in various conditions and we concluded the algorithm generates constant results regardless of the tested device and display. Moreover, when the icon is not found in the current screen, the robot identifies this situation and glides to the following screen until the icon is found. The number of hours in which the robot and the software were tested exceeds 2000 h.

As a general conclusion, the robot works very well and fulfills all the functional requirements, so it can be used for testing mobile devices. By using the video information from the camera, the robot can identify icons of various applications, correctly detect their position and tap them or interact with them in a way that is de finable by the programmer. The use of a virtual keyboard is possible by identifying the characters and figures based on features saved in a database. This way, a robust behavior was implemented, so changing the position of an icon on the testing area does not influence the behavior of the robot. Moreover, the data base can be easily extended by adding new icons or images.

The overall achieved performance is better that other competitors', being obtained at much lower costs. Also, the functionality, ergonomy and robustness of the robot make it a serious competitor on the market.

This study is partially based on a Master thesis developed in the Faculty of Automatic Control and Computer Science, University Politehnica of Bucharest.

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