Aalto University
School of Electrical Engineering
Degree Programme in Automation and Systems Technology

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An Open and General Numerical Control and Machine Vision Based Architecture for Payment Terminal Acceptance Test Automation

Master's Thesis
San Jose, May 6, 2016

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ABSTRACT OF
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Software testing is a crucial part of modern software development and it is commonly accepted fact that the earlier software defects and -errors are found, the lower the cost of correcting those will be. Early detection of errors also increases the possibility to correct them properly.

Acceptance testing is a process of comparing the developed program to the initial requirements. Acceptance testing of a system should be executed in an environment as similar as possible to the production environment of the final product. This master's thesis will discuss how to address these guidelines in automated acceptance testing environment of payment terminal software.

This master's thesis will discuss the theories related to software testing, testing of embedded systems and the challenges stated above. Master's thesis will present a proposed architecture for automated acceptance testing of payment terminals including the needed hardware and software.

Keywords: Automated Acceptance Testing, Software Testing, Payment Terminal, Robot Framework, Computer Vision, Open Source

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Ohjelmistotestaus on tärkeä osa modernia ohjelmistotuotantoa ja on yleisesti tunnustettu, että mitä aiemmin virheet ohjelmistosta löytyvät, sitä edullisempaa niiden korjaaminen tulee olemaan. Aikainen virheiden havaitseminen myös edesauttaa virheiden perusteellista ja laadukasta korjaamista.

Hyväksymistestaus on ohjelmistotestauksen vaihe, jossa kehitettyä ohjelmistoa verrataan alkuperäisiin ohjelmistovaatimuksiin. Ohjelmiston hyväksymistestaus tulisi suorittaa lopullista tuotantoympäristöä mahdollisimman hyvin vastaavassa ympäristössä. Tämä diplomityö käsittelee näitä ohjeistuistuksia maksupäätteiden automaattisen hyväksymistestauksen ympäristössä.

Tämä diplomityö käsittelee ohjelmistotestaukseen liittyvää teoriaa, sulautettujen järjestelmien testausta sekä yllä mainittuja haasteita. Lisäksi diplomityö esittelee ehdotetun ympäristön maksupäätteiden automaattiseen hyväksymistestaukseen ja käsittelee siihen tarvittuja ohjelmistoja ja fyysisiä komponentteja.

Asiasanat: Automaattinen hyväksymistestaus, ohjelmistotestaus, maksupääte, robot framework, konenäkö, avoin lähdekoodi

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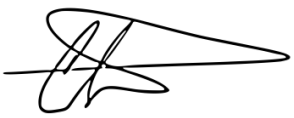


Sakari A. Pesonen

Abbreviations and Acronyms

CNC	Computer Numeric Control
UI	User Interface
LCD	Liquid Crystal Display
HMI	Human Machine Interface
BW	Black and White
PIN	Personal Identification Number
RF	Robot Framework
AAT	Automated Acceptance Test
PWM	Pulse Width Modulation
OCR	Optical Character Recognition
QA	Quality Assurance
SUT	System Under Test
BDD	Behavior-Driven Development

Contents

Chapter 1

Introduction

Software testing is a crucial part of modern software development and it is a commonly accepted fact that the earlier defects and errors in the software are found, the lower the cost of correcting those will be. Early detection of errors also increases the possibility to correct them properly. *(Myers et al., 2011)*

Acceptance testing is the process of comparing the developed program to to the initial requirements of the software *(Myers et al., 2011)*. Automated acceptance testing (AAT) phase should be executed whenever new features are added. Therefore, especially in agile software development, AAT plays an important role as new versions of software are being developed constantly. Automation can free valuable human resources from this process *(Haugset and Hanssen, 2008)* and therefore lower the overall cost of the software.

According to *Sommerville (2011)* acceptance testing of a system should be executed in an environment as similar as possible to the production environment of the final product. System should also be tested with real data rather than with a simulated sample. When software is developed for an embedded system and therefore the production environment is an actual device, in this case a payment terminal, the acceptance testing should be executed on genuine payment terminal with truly interacting through the user interface (UI) of the machine. This also leads to a situation where concerns pointed

out above are in fact being emphasized, as late detection of defects in embedded software can considerably raise the overall cost of the system *(Ebert and Jones, 2009)*.

Sommerville (2011) states that it is practically impossible to perfectly replicate the system's working environment and when considering an embedded system, this can be even harder. Buttons of the device have to be actually pressed and visual changes on the screen of the device have to be observed. In order to automate this, some sort of a test environment has to be implemented that can observe and manipulate the device through the real physical user interface, i.e. not simulating the keystrokes nor reading the LCD communication line. Some kind of joint hardware and software solution has to be created and it also has to mimic real human user as realistically as possible.

This master's thesis will discuss the theories related to software testing, testing of embedded systems and the problems stated above. In addition, this master's thesis presents an architecture for automated acceptance testing of payment terminal software including the needed hardware and software.

Research presented in this master's thesis was carried in co-operation with Eficode Oy and one of the main payment terminal software provider in the Nordic countries.

1.1 Problem Statements

In order to survey the topic of this work at an adequate level, this master's thesis presents four different problem statements. Problem statements are as follows:

1. What are the benefits of using open source software and how can the architecture be designed to maximally exploit these benefits?

2. What are the distinguishing characteristics between different payment terminals that have impact on automated acceptance testing? How can

the architecture be designed to adapt the system to different payment terminals with minimal effort?

3. What kinds of test automation approaches exist and which approach is best suited for payment terminal acceptance test automation?

4. How should test keywords used in test suites be defined to make the test suites compact and understandable? How should keywords be defined to make the tests reusable for other types of payment terminals?

1.2 Structure of the Master's Thesis

This master's thesis first discusses the theories and literature related to the topic and then presents an architecture of automated test environment for payment terminal software acceptance testing. In the first section of this master's thesis the topic is introduced, problem statements are presented and structure of this work is explained.

Second section covers the literature review of the topic of the master's thesis. Each problem statements have related subsections and individual problem statements are being discussed in those sections. Each subsection first gives an introduction from problem statement's point of view followed by the most relevant references around the topic. Subsections point out what has been done earlier and how the fundamental aspects of these previous works can be used as a basis for this work.

Third section of the master's thesis presents the proposed architecture for automated acceptance test environment for payment terminal software based on the literature review done in the previous section. Section presents the fundamental parts of hardware and software needed for this kind of an environment. This section has diagrams of proposed software architecture as well as fundamental design of the needed hardware.

Fourth and the final section concludes the research done on this master's thesis and will summarize the benefits obtained by this kind of an environ-

ment.

Chapter 2

Payment Terminal Acceptance Testing

When developing software with agile methodologies for payment terminals, i.e for embedded system, testing is a crucial part of the process. The earlier the defects and errors in the software are detected, the lower the cost and needed effort will be for correcting those *(Myers et al., 2011)*.

Motivation for this research came from a payment terminal software provider as they needed a cost efficient and simple automated acceptance test environment in order to lower the costs and speed up the acceptance testing phase of their software development.

In order to automate the acceptance testing of the payment terminals, test environment that can manipulate and observe the device through physical world has to be created. In other words, environment has to have some sort of a robot for pressing the buttons and screen of the device has to be observed. All this must be also controlled by some kind of combination of software.

Test environment that can be used in acceptance testing of payment terminals has several challenges to tackle and matters related to physical and technical aspects of the payment terminals have to be considered. This chapter discusses the background of these challenges. Customer also had a desire for open source technologies and this chapter discusses the benefits obtained

by using open source software and hardware in acceptance testing environment for payment terminals. Chapter also discusses the different approaches for acceptance testing as well as how should the test suites be defined in order to make them understandable and reusable.

2.1 Benefits of Open Source Solutions

When designing an automated acceptance testing environment from scratch, evaluation and availability of different possible components play a significant role in terms of development speed and cost. Suitability of one individual software subsystem is hard to determine just based on a manual or documentation of the product. Software has to be evaluated in terms of functionality, stability and performance and different software decisions have to be compatible with each other. Software components might also need some modification to suit the needs of the intended environment. All this applies to the hardware parts as well.

Open source software provides an advantage on these matters over closed source products as the source code is easily available *(Morgan and Finnegan, 2007)*. As open source software can be accessed free of charge, a component can be easily evaluated by trying out whether they work for the purpose or not. The evaluation can also include an analysis about how easily the open source product can be modified to suit the needs of the companies. This especially is hard to achieve with commercial closed source products as the source code is not available.

According to *Paulson et al. (2004)*, open source projects usually have fewer defects than closed source projects. Defects are found and fixed rapidly as they are reported openly to the open source community. If a defect is found during evaluation of the product, it can also be corrected by the user. By doing this the user can contribute to the project. This, on the other hand, is hardly never possible with closed software.

Paulson et al. (2004) also state that open source projects foster more cre-

ativity than closed source counterparts. This means that number of functions added over time is higher in open source projects. When using the product in some new field of use, this can be a great advantage as user can report desired features to the community and it can be added relatively quickly if the feature is considered needed by the community.

"Open source" hardware on the other hand means that details and plans of the product and parts are commonly available. This allows that parts can be manufactured and modified by anyone with knowledge and skills to suit individual needs. When detailed part descriptions are available, multiple manufacturers can fabricate the actual parts. This creates competition and therefore usually lowers the price of individual hardware components.

As the overall security of the payment terminals is a high priority, use of open source technologies can also be seen as an effort to fulfill this requirement. Open source products provide transparency to the actual users and therefore supports growing trust amongst customers.

2.2 Common Characteristics Between Payment Terminals

When designing automated test environment for different kinds of payment terminals, different physical and technical features have to be taken into account. Environment has to be able to manipulate different types of payment terminals and test structure has to be designed to adapt to the needs of different software and software versions running on the payment terminals.

Majority of payment terminals share some common characteristics as they are made for same purpose: handling card payments. Scope of this thesis is to view those payment terminals that share three main features: a keyboard, a screen and a card slot. Different types of terminals are visualized in Figure 2.1 and Figure 2.2 below.

Screens of the payment terminals differ in terms of size, placement and type. Test environment has to take into account different screen placements

and it has to support both black and white (BW) and colored displays.

Keyboards of payment terminals share majority of keys together as number keys are needed for entering the PIN code and accept- and decline-buttons are needed for accepting and canceling the payment. Keyboard layouts, however, differ between different manufacturers and even amongst different models of the same manufacturer.

Location of the chip card slot is usually on the lover edge of the payment terminal or on top of the screen of the payment terminal. Research done within this master's thesis is limited to those terminals that have the chip card slot at the lower edge of the payment terminal as this simplifies the hardware needed for test environment. This is described more in depth in section 3.2. This study is also limited to chip card readers and therefore, magnetic stripe readers and near field communication (NFC) payments are not addressed.

Figure 2.1: Two examples of payment terminals from different manufacturers. Left image from: `http://www.netskauppa.fi/images/t/24-85-PrimaryImage.image.ashx`

Figure 2.2: Example of a payment terminal which attaches to a smart phone.

2.3 Different Approaches for Test Automation

According to *Broekman and Notenboom (2003)*, testing of embedded systems and embedded system software can be very different depending on what kind of system is under testing. Mobile phones have to be tested in a very different manner than for example cruise control system in cars. Nevertheless, some general guidelines and divisions exists and should be followed.

Problem of testing a payment terminal software in an automated way can be viewed at different levels. Most abstract division can be seen if the testing is divided into two levels: white box testing and black box testing. White box testing is a method where the source code is investigated and test cases are written to test the internal logic of the program. Black box testing, on the other hand, concentrates only on the inputs and the outputs of the software. Everything between those is not in the field of interest as black box testing only focuses on whether the right input produces the wanted output. (*Myers et al. (2011)*)

Khan and Khan (2012) distinguishes these methods clearly from each other by stating that white box testing is a process where full knowledge of source code is needed in order to write the tests. Black box testing is described in a way that only fundamental aspects of the application has to be known and black box testing has no or only little relevance to internal works of the program *(Pressman, 2005)*. Black box testing techniques can be thus seen to apply for testing of working product against the initial requirements of the software. In this way white box testing can be distinguished to cover unit and integration testing part of the software testing and the black box testing can be seen covering the acceptance testing part of the testing.

As black box testing is based on the external exceptions and behavior of the software *(Khan and Khan, 2012)*, acceptance testing of the payment terminal software can be seen to follow this methodology. Intended automated testing of the payment terminals seems to also follow the acceptance testing phase of the division made by *Khan and Khan (2012)*.

Huizinga and Kolawa (2007), on the other hand, presents that test automation can be divided into several other layers that are unit testing, integration testing, system testing and acceptance testing. Unit testing is defined to cover testing of a single unit of the software's source code e.g. individual methods and functions of the software. Integration testing is described as a testing phase to verify that different parts of the software work together as a group. System testing is described as being a testing phase where hardware and software is integrated and tested to meet the requirements of the system. This can however include simulated data. Acceptance testing is represented as highest abstraction level of this division as it ensures that the final product meets its acceptance criteria defined by the customers.

Ramler et al. (2014) divides the general architecture of an embedded system into three parts. In this division the human machine interface (HMI) is the top layer. This is followed by the software running on the device and the lowest level are the hardware components of the machine which can be accessed through different analog and digital interfaces. As this master's

thesis addresses only the acceptance testing of one instance of an embedded system and as it only has to verify whether the system fulfills its acceptance testing requirements, these abstraction levels can be overlooked. Also for this purpose the black box testing technique seems to be the appropriate testing manner.

Acceptance testing of a payment terminal software can be seen as a testing phase where the UI of the device and the use cases of the device are tested at the final production level, i.e. through using the real buttons of the device under test and observing that the expected messages can be seen through the screen of the same device. This can be seen as an effort to automate a real human user using the payment terminal.

2.4 Test Suite Syntax

Test suite syntax plays a significant role in an automated acceptance testing environment of payment terminals in terms of test readability, reusability and adaptivity. When building an automated acceptance testing environment, the tests should be understandable enough that the whole development team and all of the project's stakeholders can easily adopt to the test syntax.

According to the well recognized guidelines of test automation by *Bach (1996)*, test automation and the process that it automates should be kept carefully separated. Test automation should be built in a form that it is easy to review and distinct from the process that it automates. These guidelines should be taken into account also when determining a suitable test framework and test suite syntax.

When evaluating suitable test automation frameworks, it should be recognized that shared knowledge is a key factor of successful test automation. Software projects usually involve some sort of quality assurance (QA) or even a separated QA team. Projects also tend to involve fair amount of people with no technical background or coding skills and yet their responsibilities can still involve guaranteeing the quality of the software. *Mosley and Posey*

(2002) recognizes that high level test languages help to share the knowledge amongst the people that are responsible for the product. Sharing information and knowledge amongst the project's stakeholders helps achieving the objectives of test automation and builds up the morale amongst the people that are involved.

Lowell and Stell-Smith (2003) state that acceptance tests should be easy as possible to write or otherwise people working with the project will not write the tests as the task is seen unpleasant. In order to cope with changing requirements or updated features, the tests should be easy to maintain as people have to be able to update them even if they have been written by someone else. For this reason the test cases should be human readable and understandable also to non-technical people. Test steps should be self explanatory and unambiguous.

Test cases in acceptance testing of a payment terminal contain relatively high amount of repetition as for example test step of inserting a personal identification number (PIN) code is the same whether right or wrong PIN code is inserted or whether the test case would validate a credit or debit payment. For this reason, test case syntax should be as modular as possible in order to allow reuse of keywords with different parameters. Easily reusable keywords also allows fast creation of new test cases.

Tests can essentially be written in some conventional coding language, for example Java or Python, or by using some higher level language. There are many widely used test frameworks available for conventional coding languages, for example jUnit for Java *(JUnit, n.d.)*. This, however, requires coding experience to some extent in order to be able to understand and modify existing tests or write new ones. As it is stated above, combined with the guideline for writing tests understandable enough, usage of conventional coding languages can be seen opposing the best practices. On the other hand, test case syntax must be versatile enough to accommodate different kinds of testing scenarios and needs. This leads to a situation where the abstraction level of the test cases has to be considered carefully.

```
@Test
public void validLogin() throws Exception {
    try {
        openBrowser();
        inputUsername("demo");
        inputPassword("mode");
        clickElement(By.name("Submit"));
        pageTitleShouldBe("Welcome")
    } catch (Exception e) {
        log.error(getClass().getName() + " failed. Exception:", e);
        takeScreenshot(getClass().getName() + "_failed");
        System.out.println(driver.getPageSource());
        throw e;
    }
}
```

Figure 2.3: Example of a jUnit test case that tries to login to website.

In addition to the test frameworks utilizing the use of some conventional coding language for test cases, there are also couple of well recognized tests frameworks available that use a more human-like language for writing the tests. These frameworks usually use the same libraries for interacting with the system under test (SUT) as more low level frameworks but they allow a higher level syntax in the actual test scripts. One fairly popular example of this kind of higher level test framework is Cucumber. Cucumber is an open source acceptance test framework that utilizes behavior-driven development (BDD) style *(Cucumber, n.d.)*. Cucumber uses Gherkin language that is designed to be human readable without previous knowledge of coding *(Gherkin, n.d.)*. This means that also business oriented people involved with the project can understand the test cases.

```
Scenario: Valid login to webpage
  Given that I am on the homepage
  And I have typed credentials
  When I click on link Submit
  Then the page title should be "Welcome"
```

Figure 2.4: Example of a simple Cucumber test scenario and use of Gherkin language.

Another good example of a higher level test framework is Robot Frame-

work (RF). RF is an example of generic keyword driven test automation framework *(Robot Framework, n.d.)*. RF allows creation of human readable test cases and reusability and extendability of high-level keywords is made relatively easy *(Stresnjak and Hocenski, 2011)*. *Nokia Solutions and Networks (2015)* also outlines that RF has a highly modular software architecture allowing it to be easily connected to any kind of SUT by using different test libraries.

Example of a Robot Framework test case can be seen in Figure 2.5 below. It is easy to see the intended test case execution by looking at the test case. This will be the goal for the environment proposed later on in this master's thesis.

```
*** Settings ***
Documentation     A test suite with a single test for valid login.
...               This test has a workflow that is created using keywords in
...               the imported resource file.
Resource          resource.txt

*** Test Cases ***
Valid Login
    Open Browser To Login Page
    Input Username    demo
    Input Password    mode
    Submit Credentials
    Welcome Page Should Be Open
    [Teardown]    Close Browser
```

Figure 2.5: Example of a simple test suite. Source: `http://robotframework.org`

Chapter 3

Proposed Architecture

Based on the aspects pointed out on Section **??**, this part of the master's thesis will present a proposed architecture for automated acceptance testing environment for payment terminal software. Components of the environment can be divided into hardware and software components and this Section is divided accordingly.

Motivation for this project came from the customer and Eficode Oy took responsibility of implementing the system according to the best practices of the industry. This proposal was initial plan for the project and it will be presented in this Section.

3.1 Overview

When planning an automated acceptance test environment for payment terminal software, environment has to be highly adaptive for different types of hardware and software features of different payment terminal models. This proposal was done for one payment terminal software provider and they had several different models of payment terminals and altogether 51 different software configurations for those devices.

Security is a top priority of payment terminal electronics and software and it is not possible to access internals of the payment terminal hardware.

This means that AAT environment has to be able to manipulate the physical interface of the device. This also creates requirement for supporting different types of keyboard layouts and screen locations. In other words, environment has to be non dependent on single manufacturer or payment terminal model.

One of the requirements for the AAT environment was also use of open source technologies. For the reasons pointed out in Section 2.1, customer wanted that the environment is as open as possible. This also creates reputation and visibility regarding the security matters.

Other requirements for the AAT environment was simplicity, low cost, low need for maintenance and ability to run the tests 24/7.

3.2 Hardware

Hardware for this proposal was intendedly kept simple and low-cost as possible. This proposal presents the use of just one Raspberry Pi 2 Mode B computer as a main computer for AAT environment *(Raspberry Pi 2, n.d.)*. Raspberry Pi 2 in relatively inexpensive compared to its computing power and it can also run a full Linux operating system. It is small sized and does not require any cooling equipment. Therefore, it suites well to this project as it can be situated easily to the environment and can be run over the clock without concerns about wearing cooling fans for example.

3.2.1 The Robot

As internal electronics of the payment terminals are not accessible for security reasons, some sort of a robot is needed to be able to manipulate the physical UI of the payment terminals. The robot should therefore be able to accommodate different types of payment terminals and be able to press all types of buttons in question. Low cost and low need for maintenance are also requirements for this robot requested by the customer. The robot should also be able to manipulate multiple payment terminals at the same time in order to allow parallel execution of acceptance tests. This is intended to speed

up the overall process as the same tests have to be run on different models of payment terminals. An other option would be to make the changing of the device under test easy and fast so that the manual work required can be minimized.

One of the options for automating the pressing of the buttons of the payment terminals would be to manufacture a frame on top the payment terminal which would have actuators for pressing each button. This would allow quick entering of key sequences and simultaneous pressing of multiple buttons. Hobby grade servo motors could be used as actuators in order to make this solution affordable. However, in order to support different kind of keyboard layouts and different sized payment terminals, the solution would require advanced mechanical engineering and thus the price of this solution could rise to become non cost-effective regarding the scope of this project and master's thesis. For these reasons this option for payment terminal manipulator is not proposed.

Other option for automatically pressing the buttons of the payment terminals would be utilizing the use of robotic arm. A robotic arm would be able to emulate a human user rather accurately and depending on the used robotic arm, simultaneous pressing of the buttons could also be possible. Drawback on the use a robotic arm is the relatively high purchasing price of accurate and powerful robotic arms. This could be overcame by manufacturing the robotic arm with own resources and using some openly available plans *(BCN3D-Moveo, n.d.)* but this would require extensive use of time for building the arm from bottom up. For these reasons the use robotic arm is not proposed.

Third option for automating the key strokes of the payment terminal usage would be to use a portal robot. For pressing of one key of the payment terminal at a time would need a portal robot with at least 3 degrees of freedom. For the scope of this project and master's thesis this would be enough as it is only required to press one button of the payment terminal at a time. Portal robot would also be easily able to adapt to different kinds

of keyboard layouts and payment terminal sizes as it can travel across any coordinates within its workspace. By choosing a portal robot with a right sized work space, it could be also possible to accommodate multiple payment terminals to the workspace at the same time. This would allow the execution of parallel acceptance tests within several different devices at the same time. For these reasons the use of a portal robot for manipulating the buttons of the payment terminals is proposed.

The master's thesis proposes the use of ShapeOko 2 3-axis Computer Numerical Control (CNC) milling machine to be used as a manipulator *(ShapeOko 2, n.d.)*. Even though the machine is intended for milling purposes, it can be turned into a portal robot when milling tool is removed.

ShapeOko 2 is an open-source project and plans of the machine are openly available on their GitHub *(ShapeOko 2 Github, n.d.)*. This allows easy modifications to the hardware parts of the robot if needed.

ShapeOko 2 is controlled by an Arduino board running a program called GRBL *(GRBL, n.d.)*. Controlling program is an open source, high performance G-code interpreter and it is used for controlling CNC milling machines in general *(ShapeOko 2, n.d.)*. G-code command are sent from Raspberry Pi 2 to the Arduino on the robot using serial communication.

Robot should be equipped with a pushing tool that can be manipulate the buttons. Pushing tool can be easily manufactured using for example 3D printing techniques.

3.2.2 Computer Vision Hardware

In order to automate human interaction with the payment terminals, AAT environment has to be able to observe the changing content on the screen of the payment terminal. As stated earlier, internal electronics are not accessible due to the security measures and this disallows for example the possibly to hack the LCD communication line of the payment terminal in order to retrieve the image on the screen programmatically.

Therefore AAT environment also requires computer vision as changes

on the screen have to be observed visually. Manufacturer of Raspberry Pi offers low-price solution for this as a form of Raspberry Pi Camera Module *(Raspberry Pi Camera Module, n.d.)*. This module is proposed for use in computer vision tasks of the AAT environment.

As the size and the location of the display differs between different models of payment terminals, optical hardware has to be able to adapt to different kinds of imaging circumstances. As it is proposed that working area of the robot could be equipped with several payment terminals at the same time, also the displays of the payment terminals have to be able to be read regardless of the number of the devices under test.

One solution for this could be equipping the AAT environment with multiple stationary cameras, more precisely one camera per each device under test. If the cameras would be stationary, this would create boundaries for the location and the size of payment terminal displays depending on the location of the optical hardware. Portal robot proposed also has a rigid structure moving on top of the devices under test and this could cause blocking of the visual contact between camera and the display of the payment terminal.

An other solution would be having a moving camera that could be driven to a needed location in order to perform machine vision tasks. Location of the display could be configures regarding to the payment terminal model and this solution would adapt easily for different kinds of display layouts. Moving of the camera equipment can be achieved easily by attaching the camera directly to the portal robot. This will however exclude the ability to simultaneously pressing the buttons and reading the screen as robot has to be driven to certain position for capturing the image from the display. Regardless of this limitation, this solution is proposed. More precisely, it is proposed to situate the camera to the Z-axis assembly of the robot to the other side in respect to the pushing tool. This would minimize the required transitions when changing from pressing the buttons to capturing the images as the displays are typically located on top the numeric keypads on the payment terminals.

3.2.3 Card Feeder

In addition to the manipulation of the payment terminal buttons, also the card feeding functionality has to be automated. One option to accomplish this functionality would be using the ShapeOko 2 robot for inserting and removing the card from the payment terminal. This would require some kind of an attachment to the payment card in order to make the manipulation of the card possible with the same tool that is used to push the buttons of the devices under test. In this case the AAT environment software would also require some kind of reset functionality in case the software would crash and the position of the card would be lost. Manipulation of the payment cards with the ShapeOko 2 robot would also make overall testing process slower as it would not be possible to press the buttons while inserting or removing the payment card to or from the payment terminal.

Other option would be manufacturing some kind of generally adaptable card feeders that could be used with different kinds of payment terminals. This solution would allow simultaneously inserting and removing of the payment card while manipulating the buttons with the robot. Advantage of this solution would also be that card feeders could know their state even if the software would crash and the reset functionality would be more simple to implement.

As insertion and removal of the credit card might be hard to accomplish in a simple way using just the robot described in previous section. This work proposes the use of generally designed card feeders to accomplish this task. Proposed card feeders consist of 3D printed base plate that attaches to the payment terminal, servo motor and 3D printed tray that attaches to the servo and to the credit card.

Card feeders are designed in a way that they can be used with any types payment terminals that have the card slot at the bottom edge of the device. Standard hobby servos are used as servo motors in order to keep the cost of the setup low.

Arduino board will be used to drive the servos as it can easily provide

the needed pulse width modulated (PWM) signal for the servos. Arduino is suggested in order to ensure quality and accuracy of the PWM signal compared to what can be produced easily with non real time operating system running on the Raspberry Pi. Raspberry Pi on the machine will communicate with Arduino through serial communication.

3.3 Software

As stated in the Section 4.2.6, automated acceptance tests should be simple and understandable enough to actually make the automated testing efficient and beneficial. Open source solutions should be favored as this was requested by the customer and to achieve benefits described in the Section 2.1. For these reasons software decisions of the AAT environment should be carefully considered in order to achieve good maintainability, compatibility and overall simplicity.

For software part of this AAT environment, Raspbian Wheezy is proposed for operating system. Raspbian is the official supported operating system for Raspberry Pi by Raspberry Pi Foundation *(Raspbian, n.d.)*. Raspbian is based on widely used Debian Unix-like operating system. This allows the use of components developed for Debian to be used with this AAT environment.

3.3.1 Test Framework

Based on the guidelines and comparison presented in Section 2.4, the choice for test framework was considered in order to achieve the best usability, versatility and functionality. In order to maximize these measures, Robot Framework is proposed for the test framework. RF is an open-source, generic, keyword-driven test automation framework that has human readable test case syntax *(Nokia Solutions and Networks, 2015)*, *(Robot Framework, n.d.)*.

Robot Framework also has highly modular software architecture *(Nokia Solutions and Networks, 2015)* and this allows the framework to be used with any kinds of testing libraries to connect to the system under test. This

feature can be seen as a great advantage when implementing test libraries for machine control and computer vision (Section 3.3.2). Illustration of this modular architecture can be seen in Figure 3.1 below.

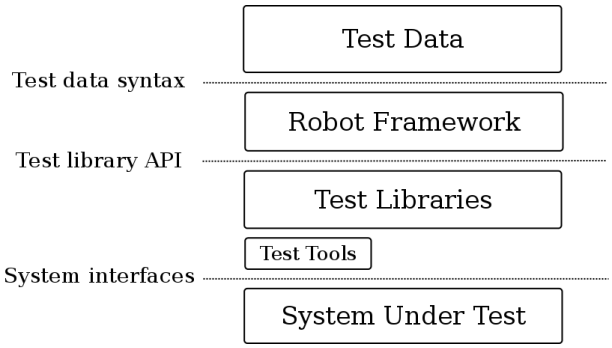


Figure 3.1: High level modular architecture. Source: `http://robotframework.org/img/architecture-big.png`

When RF tests are being run, it generates clear report and log files of the test case execution results (*(Nokia Solutions and Networks, 2015)*). These files offer high level view of all test cases and step-by-step descriptions of individual test cases in order to make the debugging more easy.

Example of intended test case can be seen in Figure 3.2. This test case describes automated RF acceptance test for entering invalid PIN code when trying to execute card purchase.

```
*** Settings ***

Documentation       A test suite for testing the machine movement and OCR
Resource            resource.txt
Test Teardown       Run Keywords    Remove Card    Go Home And Close Connection

*** Variables ***

${DEVICE_NUMBER}    1

*** Test Cases ***

Test Run For Device 1
    Set Home And Initialize    ${DEVICE_NUMBER}
    Press    red
    Screen Should Contain Text    Terminal ready
    Press    2    0    0    0
    Screen Should Contain Text    20,00
    Press    green
    Screen Should Contain Text    card
    Insert Card
    Press    1    4    5    2
    Press    green
    Screen Should Contain Text    failed
    Remove Card
    Screen Should Contain Text    Terminal ready

*** Keywords ***

Insert Card
    Card In    ${DEVICE_NUMBER}

Remove Card
    Card Out    ${DEVICE_NUMBER}
```

Figure 3.2: Example test case for invalid PIN code test

3.3.2 Test Libraries

As can be seen on Figure 3.1, architecture requires external libraries to connect to the system under test. In the case of this AAT environment those libraries would be a library for machine control, a library for computer vision and a library for card feeder manipulation. All these libraries can be written using Python programming language that is supported out of the box by Robot Framework (*(Robot Framework, n.d.)*).

For machine control library, the environment has to be able to send G-code command through USB serial communication to Arduino on the robot. For this pySerial Python library is proposed as it includes implementation of the needed serial communication functionalities (*(pySerial, n.d.)*).

For the computer vision task of the environment, textual messages on the display are usually those that need to be verified. For this, character recognition is needed. Open source optical character recognition (OCR) engine

called Tesseract OCR is proposed (*(Tesseract OCR, n.d.)*). It was initially developed by HP but since 2006 it has been developed by Google. In order to use Tesseract OCR with Python, pytesseract wrapper is needed (*(Pytesseract, n.d.)*).

Library for controlling the card feeders is the most simplest one of these three libraries. For this, pySerial Python library is also proposed to send the serial communication command to the Arduino controlling the card feeders. Library will handle sending of control commands to the Arduino controlling the card feeder servo motors.

Chapter 4

Results and Evaluation

This chapter covers the subsystems and steps taken that were needed to achieve the testing environment described in Chapter 3. This chapter first discusses the arrangements related to the hardware of the framework and then software related arrangements are presented and described. After presenting the built framework, achieved results are discussed and finally the test environment presented in this thesis is evaluated.

4.1 Hardware Arrangements

AAT environment presented in this master's thesis consists of several different hardware components. Environment had to be a smooth combination of manipulation and computing hardware. The hardware architecture is thought to be modular in a sense that every component has a specific functionality. This allows easy maintenance and upgrade of each subsystem.

As stated in Chapter 3, one of the requirements for this AAT environment was affordable price. For this reason hardware decisions have been made taking quality-price ratio into consideration and hobby-grade electronics were used widely through out the environment. 3D printing was also utilized as a manufacturing technique of custom made components for its relatively low manufacturing price and relatively acceptable quality of outputted plastic

parts.

Main components of the AAT environment are the robot that handles the manipulation of the payment terminals, Raspberry Pi 2 Model B single-board computer which was used as a main computer of the environment, two Arduino Uno boards for more specific control needs of certain components, camera for machine vision and 3D printed payment card feeders for the payment terminals. These subsystems and components are described in following subsections.

4.1.1 The Robot

As suggested in Section 3.2.1, ShapeOko 2 open-source 3-axis CNC milling machine was used as robot manipulating the payment terminals. ShapeOko was built according to the instructions found from the homepage of the project *(ShapeOko 2, n.d.)*. Construction was altered only regarding to the tool that was used as the spindle motor was substituted by 3D printed pushing tool.

ShapeOko 2 has a working area of about 300 mm x 300 mm x 60 mm and this means that it can accommodate up to three payment terminals at same time to the working area. This allows parallel test case execution i.e. test cases can be run at the same time with different terminals. Arrangement of the devices was implemented by dividing the work area into three sections. Each payment terminal was attached to a standard sized MDF-plate and each section of the working are can accommodate one of these MDF-plates. Holes were drilled in to the working area and nuts were inserted in to these holes at the back of the work bench. MDF-plates attach to these holes with screws enabling easy installation and removal of plates with different models of payment terminals. MDF-plates can be observed in Figure 4.6.

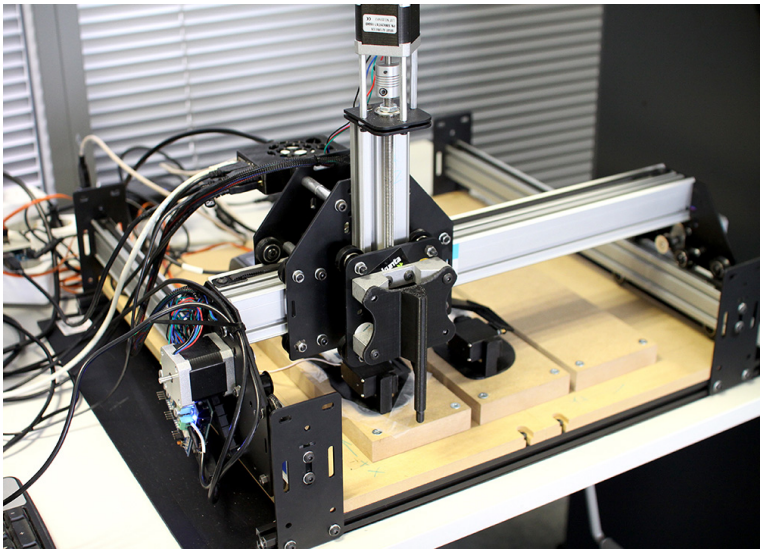


Figure 4.1: Robot in its production state.

Each axis of the robot is controlled by stepper motors. Use of stepper motors instead of servo motors offers affordable way of controlling each axis in a relatively fast and reliable manner. X- and Z- axises are both manipulated using one stepper motor on each axle and bigger Y-axis is manipulated using two parallel stepper motors. Manipulation of payment terminal buttons stresses the machine much less than actual milling of materials that the machine is designed for and this allows faster movement of the machine that would be possible when executing actual milling job.

The robot was controlled using G-code that was sent from the main computer to an Arduino Uno attached to the robot. Arduino Uno and the main computer were connected via USB connection. More detailed description of the electronics can be found from Section 4.1.2.

Section 3.2.1 suggested equipping the robot with a pushing tool and this was implemented to the final solution by 3D printing the tool from PLA plastic. Tool consisted of two parts: cylindrical beam and a stem inside of it. Stem slides inside the beam and the two parts are segregated with a spring. Spring provides the needed attenuation in order to forgive slight

misalignments and too long trajectories when pushing the buttons of the payment terminals. Pushing tool can be observed in Figure 4.2 and Figure 4.1.

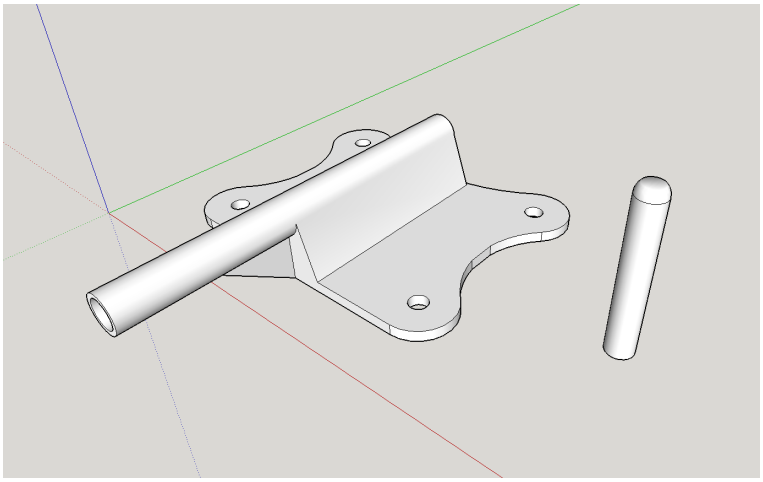


Figure 4.2: CAD design of the pushing tool. Metal spring is inserted inside to the cylinder and the stem on the right side of the image slides to the cylinder.

4.1.2 Computing Hardware

Raspberry Pi 2 Model B single-board computer is used as a main computer of the AAT environment. Raspberry Pi provides optimal computing power compared to it's price and has big community of users and developers world wide. 3D printed enclosure was manufactured to protect the computer board and it was attached to the moving Z-axis assembly of the robot.

In addition to the Raspberry Pi 2, the robot also has two Arduino Uno boards for handling some specific functionalities of the AAT environment. One Arduino Uno is interpreting the G-code commands sent from the Raspberry Pi and it is connected to the stepper motors of the robot through a stepper motor driver shield *(grblShield, n.d.)*.

Second Arduino Uno is handling the servo motor control of the card feeders. It is connected to the Raspberry Pi via USB connection and control commands to Arduino Uno are sent using serial communication. Arduino Uno board provides PWM signal to the servo motors and can accommodate three card feeders at the same time. Self-made circuit board was fabricated and attached on top of the Arduino Uno board in order to make connecting the servo motor cables easy.

Connection diagram and main electronic components are visualized in Figure 4.3.

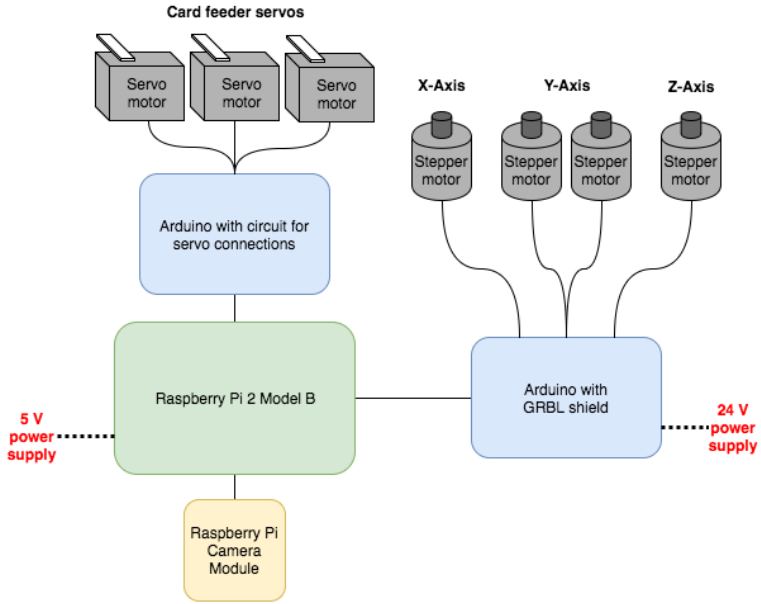


Figure 4.3: Main electronic components and connection diagram of the robot. Note that Y-axis is manipulated using two stepper motors.

4.1.3 Camera Arrangements

As suggested in Section 3.2.2, Raspberry Pi's own camera module was used for machine vision hardware. Camera was attached to the bottom of the Raspberry Pi's enclosure and the enclosure was attached to the Z-axis as-

sembly of the robot to the opposite side where the pushing tool is. Camera can be moved within the X- and Y-axis. Z-axis movement of the camera isn't possible. Depth of focus of the camera provides clear image of the screen even when the distance between the lens and the screen differs slightly between different payment terminal models. Camera attachment can be seen in Figure 4.4.

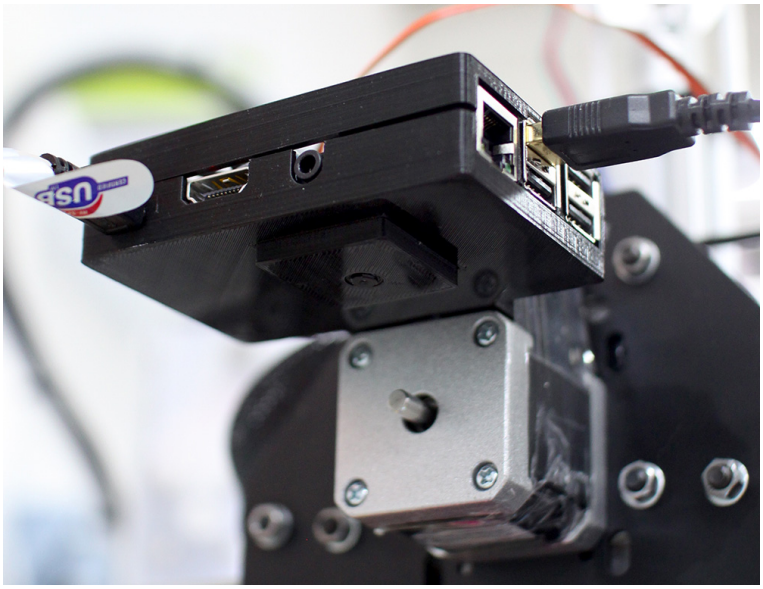


Figure 4.4: Camera is attached to the bottom of the Raspberry Pi's enclosure. Image also shows the attachment of the Raspberry Pi enclosure to the Z-axis assembly of the robot.

4.1.4 Card Feeder Arrangements

As suggested in Section 3.2.3, card feeder structures were 3D printed using PLA plastic. Finalized card feeders consisted of bottom plate, payment card holder and servo motor. Servo motor attaches directly to the bottom plate and card holder attaches to the arm of the servo motor.

Simplistic design can be used with different kinds of payment terminals which have the card slot at the bottom edge of the device. Flexibility pro-

vided by the plastic structure and the payment card itself allows the solution to be compatible with most of the payment terminals of this type. Design of the card feeders is presented in Figure 4.5. Figure 4.6 shows ready part installed to the environment presenting the servo installation and attachment of the card holder to the servo arm.

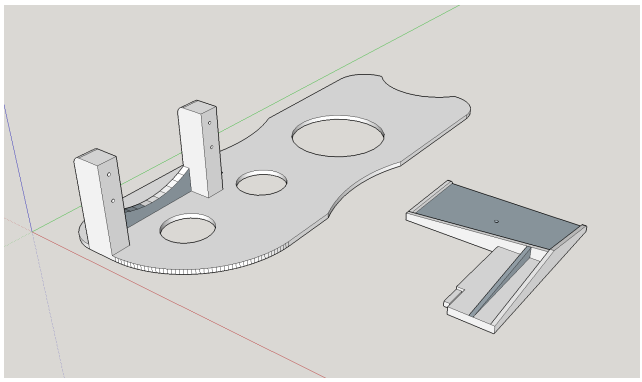


Figure 4.5: CAD design of the card feeder. Servo motor attaches to the bigger plate on the left and card holder on the right attaches to the arm of the servo motor. Card holder is designed to fit standard sized payment card.

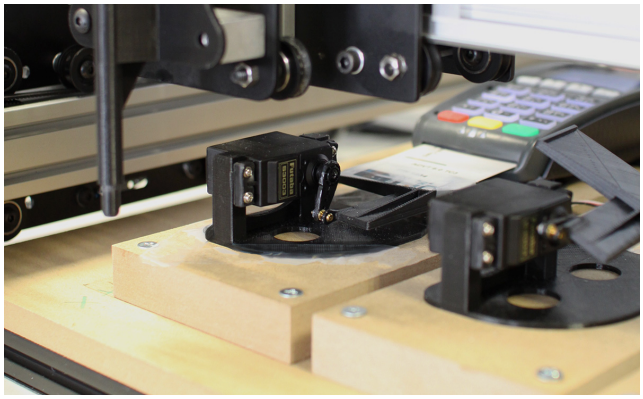


Figure 4.6: Card feeder installed to the environment. Image also presents the idea of MDF-plates described in Section 4.1.1.

4.2 Software Arrangements

As proposed in Section 3.3, this chapter describes the decisions and arrangements regarding to the software point of view of the AAT environment. Proposal was followed rather loyally though some additional arrangements had to be implemented to the environment in order to increase usability and effectiveness.

Modular architecture was implemented also to the software level similar to the hardware level. Implementation only included open source or self made software components from the operating system to individual software libraries used in the AAT environment.

This section describes the individual software components of the AAT environment and their usage and function in the whole system. System configuration, test framework and libraries and the final test suite syntax are presented.

4.2.1 Software Architecture

As suggested in the Section 3.3, Raspbian Wheesy Debian-based operating system was used with the Rasbperry Pi 2 Model B single-board computer. Operating system was used to run the test framework, test libraries and other software components and to handle the communication with different subsystems of the AAT environment.

Robot Framework was used as a test framework for its modularity, simplicity and versatility. RF was run on top of Python runtime environment and all test libraries were written using Python programming language *(Python, n.d.)*. Python test libraries were implemented to handle the needed serial communication to the Arduino board on ShapeOko 2 and to the other Arduino board used for controlling the card feeder servo motors. Picamera Python library was used for providing the needed Python interface for communication with the Raspberry Pi camera module *(Picamera, n.d.)*. Overall visualization of the software architecture can be observed in Figure 4.9.

As different keyboard layouts have to be supported, configuration files for keyboard layouts were implemented. There are two types of configuration files: one for device locations in the working area of the robot and one for each keyboard layout. Configuration file for device locations defines the coordinates of "number one" -button and the height in respect of Z-axis where the transitions over the buttons are safe. This is Z-axis coordinate is used for transitions between pressings of buttons.

Configuration file for each keyboard layout defines the button locations in respect to the "number one" -button. Z-axis coordinates defined in this file define the distance from the safe transition height to the full press of the button. Location of the screen of each device is also defined in these configuration files and it is used for driving the robot to the optimal place for capturing the image of the display of the device under test.

By dividing the configuration files into different levels enables easy modification and adding of new device configurations. Desired configurations can be also changed easily at the test case level. Examples of these configuration files can be observed in Figure 4.7 and in Figure 4.8.

```
0.0 258.0 24.0          Device 1 (x- and y-coordinates of the device and z-position for changing tool position)
100.0 258.0 24.0        Device 2
200.0 150.0 24.0        Device 3
```

Figure 4.7: Configuration file for device locations in the working area of the robot.

```
0.0 0.0 8.0          One (X- and Y-coordinates and Z-position for pressing button)
17.0 0.0 8.0         Two
38.0 0.0 8.0         Three
0.0 -13.0 7.0        Four
17.0 -13.0 7.0       Five
38.0 -13.0 7.0       Six
0.0 -28.0 6.0        Seven
17.0 -28.0 6.0       Eight
38.0 -28.0 6.0       Nine
0.0 -40.0 4.0        Star
17.0 -40.0 4.0       Zero
38.0 -40.0 4.0       Hashtag
0.0 -54.0 2.0        Red
17.0 -54.0 2.0       Yellow
38.0 -54.0 2.0       Green
30.0 -180.0          Camera
0.0 18.0 10.0        F1
10.0 18.0 10.0       F2
25.0 18.0 10.0       F3
43.0 18.0 10.0       F4
```

Figure 4.8: Example of a configuration file of a device keyboard layout.

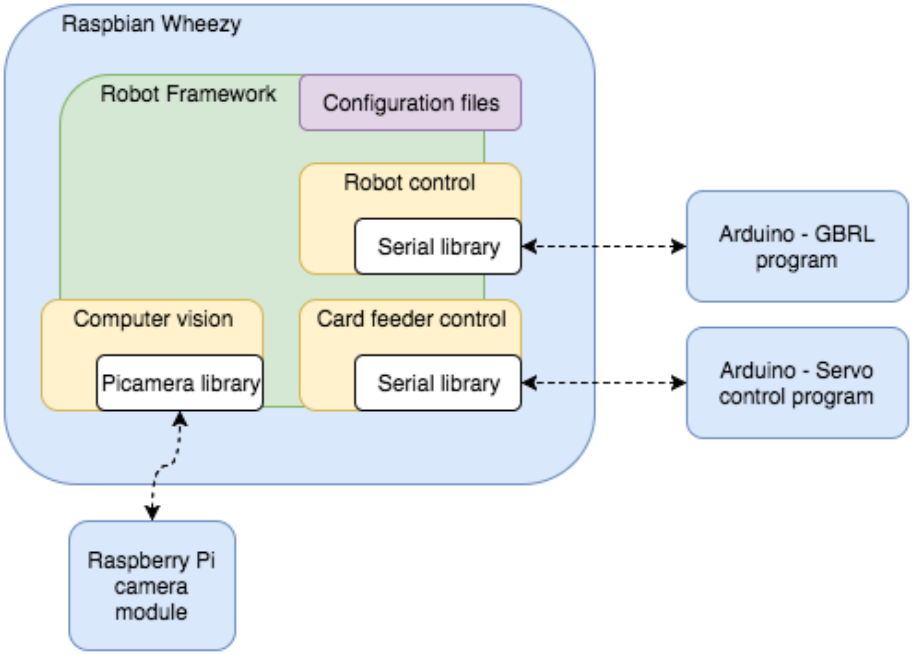


Figure 4.9: Simplified visualization of the software architecture of the AAT environment.

4.2.2 Robot Framework Test Framework

As proposed in Section 3.3.1, Robot Framework was used as a test framework for AAT environment presented in this master's thesis. RF was equipped with several different test libraries to achieve the desired functionality of the AAT environment.

RF is a generic keyword driven test framework and this means that the keywords used for different test steps can be defined in desired level of abstraction, lowest being that one keyword would handle only one library method and highest being that one keyword would be responsible of whole test case. This allows high versatility but also makes the developer responsible of writing test cases according to commonly accepted best practices. Test cases developed in the scope of this master's thesis were developed to be as human readable as possible and to mimic the mindset of human when dividing the test cases into steps. This naturally depends of the person that is thinking the test steps but it was attempted to make the devision between each test steps as clear as possible.

Test cases and steps were also divided into different keywords in a sense of reusability. According to *Martin (2009)* any code written should be as readable and understandable as possible and these directions were used as guidelines when the test cases were implemented. *Martin (2009)* also advices that code should be written in highly modular manner and this was followed when the keywords were combined in different abstraction levels.

Keywords used in test cases were defined in three different levels: test library keywords, shared keywords and test suite specific keywords. Test library keywords are the most low level keywords and implement the functionality between RF and SUT using different interfaces. These were written using Python language.

AAT environment also introduced a resource file for combining the keywords that were shared with different test suites. Abstraction level of keywords found from this file can be qualified as middle or high level. Resource file is also used for defining common test libraries between test suites and

common set-up and tear-down commands of test cases and suites. Resource file is imported to each test suite file. Example of partial resource file can be seen in Figure 4.10

Based on the work done in this master's thesis, open source RF library was published *(Robot Framework CNC Library, n.d.)*. This library can be used for easy controlling of devices that use serial communication as a communication protocol and are controlled using G-code commands. library is intended for use in similar circumstances described in this master's thesis but can also be used as general G-code control library for Robot Framework.

```
*** Settings ***

Documentation  A resource for payment terminal acceptance testing

Library     ../libs/StreamLibrary.py
Library     ../libs/OCRLibrary.py
Library     ../libs/ArduinoServoLibrary.py

*** Variables ***

${IMAGE_PATH}     ../ocr-images
${CONF_FILE_PATH}     ../conf

*** Keywords ***

Open Connection
    StreamLibrary.OpenConnection

Go Home And Close Connection
    Go To Home
    Lower Tool
    Close Connection
```

Figure 4.10: An example of a partial resource file for Robot Framework tests.

4.2.3 Robot Control and Card Feeder Libraries

For sending the control commands to the ShapeOko 2 robot with Robot Framework, robot control library was implemented using Python language. Control commands for the robot robot are given using G-code commands and

those are being sent using serial communication protocol. Library defines keywords that can be used withing the keyword definitions and test cases of the RF acceptance tests.

Desired G-code commands are produces in respect to the configuration files described in Section 4.2.1. Library reads the coordinates of the devices and different buttons and by combining these forms the needed G-code command to drive the robot into particular location. Library has *go_to()* -method which takes the button name as parameter to drive the robot into desired position. *press_button()* -method is used to press the button when to robot is reached the desired position on top of the button.

Library also has methods for setting the home position which is used in the initialization of the library after it has been imported into RF test. Library also implements methods for going into home position, going to the right position for image capture in respect of the device under test and individual methods for lovering and raising the pushing tool of the robot. These can be used as a keywords within the test cases.

For controlling the card feeder another test library was also implemented using Python language. Control command for card feeder Arduino board are being sent using serial communication and library takes care of this interaction between the RF and the Arduino board. Card feeder library only implements *update()* -method that takes the angle and the card feeder number as parameters. This method sends the control command to the Arduino board of the card feeders and can be used as a keyword within the RF keywords or test cases.

4.2.4 Card Feeder Software

For controlling the servo motors of the card feeders with Arduino board, an Arduino program was developed. As described in previous section, the control commands are sent to the Arduino using serial communication. Messages read by Arduino consists of two parts: card feeder number and desired angle of the servo. After receiving the message, Arduino program interprets

the device number and angle from it and uses switch-case code structure to control the appropriate card feeder.

Servo motors of the card feeders are controlled using PWM control signals. Arduino program can drive the servo motors to every angle that the servo motor is capable of moving and the angles of inserting the card and removing the card can be defined in the test case level.

4.2.5 Computer Vision Library

As proposed in Section 3.3.2, computer vision library was implemented for extracting the optical features on the display to format that can be interpreted programmatically. The main task of the computer vision library is to interpret the text displayed in the screen of the payment terminal.

Computer vision library was implemented using Python language and Tesseract optical character recognition (OCR) engine is used to extract the found characters to textual format. Image captured by the Raspberry Pi camera module is slightly manipulated in order to make the text extraction more efficient and reliable. Image manipulations are made using OpenCV Python library *(OpenCV, n.d.)*. Image is first being slightly blurred using Gaussian blur filter in order to reduce the amount of disturbance caused by pixel edges of the display. Color space of the image is then converted to gray-scale. Finally, the gray-scale image is converted into binary BW image by comparing the pixel value to certain threshold value. Threshold value is adjusted according to the screen brightness and lightning conditions of the space where the robot is situated. These image manipulations produce an image where text in the display is clearly distinguishable from the other features providing good foundation for the character recognition.

Tesseract OCR engine can basically extract any kind of common characters from the image and this can sometimes cause unwanted noise as small dirt particles and disturbances in the image can be interpreted to some exotic special character. In order to make the task of OCR engine easier in addition to the binary BW image, possible characters are white-

listed. Final list of possible characters that are accepted by the OCR engine is: "ABCDEFGHIJKLMNOPQRSTUVWXYZabcdefghijklmnopqrstuvwxyz0123456789,€". This also helps the OCR engine to distinguish right characters from possible similar looking foreign-language counterparts.

Computer vision library outputs all found textual features from the source image and validation of right content is being done using Robot Framework.

4.2.6 Test Syntax

Robot Framework files are divided into different parts that all have specific functionality and purpose. This helps to observe the different configurations and used keywords within the test suite in order to gain comprehension of the functionality of the particular file. As mentioned earlier, the project structure is divided into shared resource file and individual test suite files. Same syntax applies to both kinds of files, only the scope of the definitions changes according to the type of the file. Resource file is divided into three sections: settings, variables and keywords. Test suite files are divided into four sections: settings, variables, test cases and keywords.

Settings section of the file define all the needed settings for executing the test cases. This includes all resource and library imports and test setup and teardown definitions. In this project all the library imports are done within the resource file and the resource file is imported to the test suites in the settings section of the test suite files. Test teaedowns are also defined at test suite level.

Variables section defines all the used variables within the test cases. Variables section of the resource file are used for defining used directory paths for e.g. location of the image directory used by the computer vision and location of the configuration files of the device location configuration file and configuration files of different keyboard layouts of the payment terminals. Variables are defined using $\${variable}$ annotation.

Test cases section of the test suite files are used for defining all the test cases within the test suite and test steps of the test cases. Test cases are

defined by naming them in the firs line and then defining the test steps by indenting the names of the used keywords with at least two space characters under the name of the test case.

Keywords are defined in the same way as test cases. Each keyword definition begins with the name of the keyword followed by indented names of used lower level keywords or library methods. Keywords can be built modularly into different layers by using lower lever keywords in higher level keyword definitions.

Example test case can be seen in Figure 3.2 as proposed test case syntax was followed.

4.2.7 Test Results

For the testing to be actually useful and informative, clear test reports and error descriptions has to be generated. Robot Framework is useful for this purpose as it automatically generates two types of clear and easily understandable test result files after executing the test suite under examination. These files are outputted in *.html* format making it able examine the reports interactively using web browser.

report.html file can be user to review the overall status of executed test suites and cases. This report gives overall view to the testing project and different outcomes of the tests are marked in bright colors green representing passed test and red representing failed test. Example of passed test report file can be seen in Figure 4.11 and example of failed test report can be seen in Figure 4.11.

log.html file contains more detailed representation of the test cases. Each test step is shown here and the internal keywords and library methods used by the keyword are layered under each test step. If test step fails during the test execution, the stack trace of that particular command is added to the log file and can be easily observed. Example of log file can be seen in Appendix A.

Robot Frameworks also allows setting up threshold limits for test suites

that are used to determine whether the test suite is passed or failed. For example, the threshold can be set to 90 % and if over 90 % of test cases within the test suite are passed, the test suite is being considered passed. Test cases can also be marked as critical meaning that if those particular test cases fail, the test suite is never considered as passed.

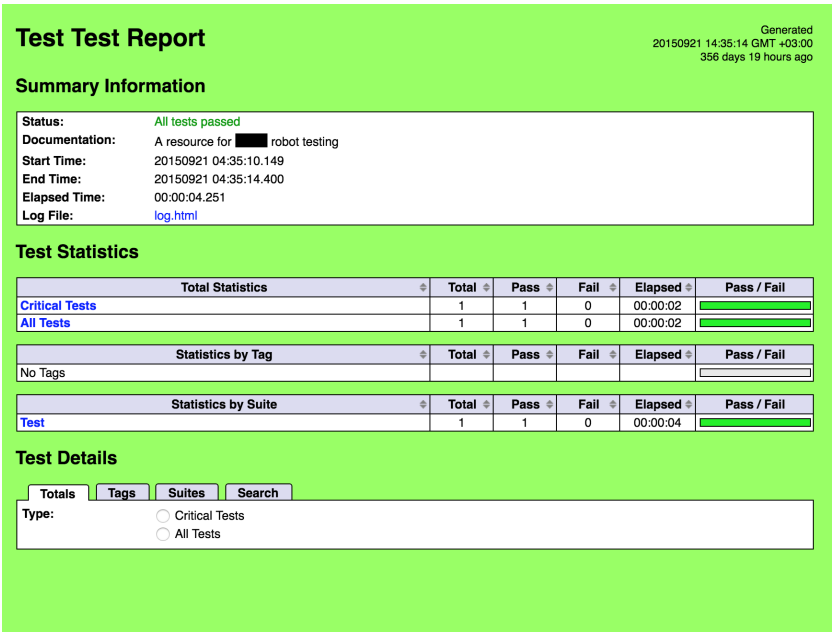
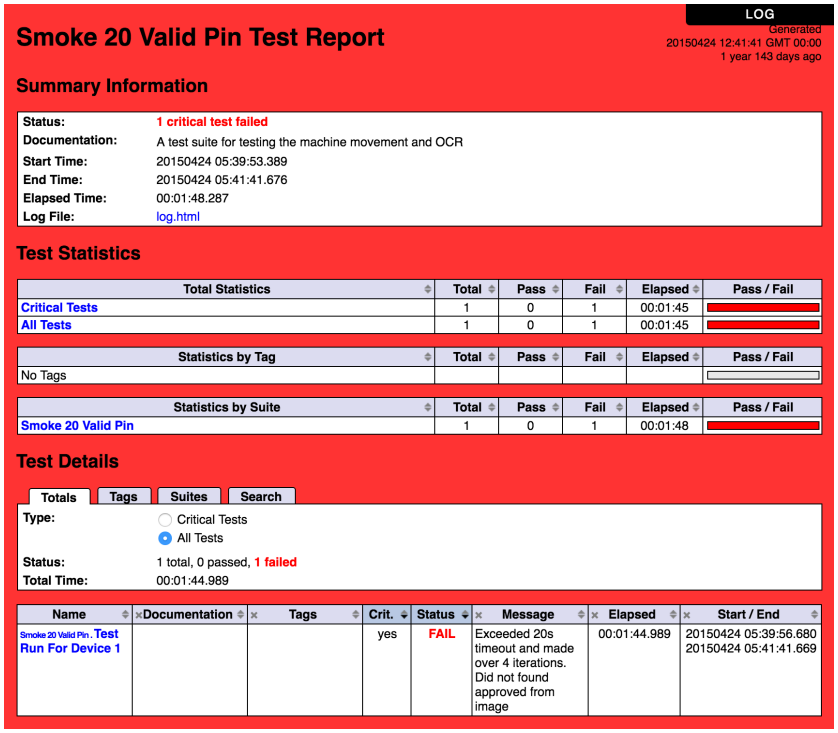


Figure 4.11: Report of passed tests.



LOG

Generated
20150424 12:41:41 GMT 00:00
1 year 143 days ago

Smoke 20 Valid Pin Test Report

Summary Information

Status:	1 critical test failed
Documentation:	A test suite for testing the machine movement and OCR
Start Time:	20150424 05:39:53.389
End Time:	20150424 05:41:41.676
Elapsed Time:	00:01:48.287
Log File:	log.html

Test Statistics

Total Statistics	Total	Pass	Fail	Elapsed	Pass / Fail
Critical Tests	1	0	1	00:01:45	
All Tests	1	0	1	00:01:45	

Statistics by Tag	Total	Pass	Fail	Elapsed	Pass / Fail
No Tags					

Statistics by Suite	Total	Pass	Fail	Elapsed	Pass / Fail
Smoke 20 Valid Pin	1	0	1	00:01:48	

Test Details

Totals | Tags | Suites | Search

Type: Critical Tests / All Tests

Status: 1 total, 0 passed, 1 failed

Total Time: 00:01:44.989

Name	Documentation	Tags	Crit.	Status	Message	Elapsed	Start / End
Smoke 20 Valid Pin. Test Run For Device 1			yes	FAIL	Exceeded 20s timeout and made over 4 iterations. Did not found approved from image	00:01:44.989	20150424 05:39:56.680 20150424 05:41:41.669

Figure 4.12: Report of failed tests.

Chapter 5

Discussion

At this point, you will have some insightful thoughts on your implementation and you may have ideas on what could be done in the future. This chapter is a good place to discuss your thesis as a whole and to show your professor that you have really understood some non-trivial aspects of the methods you used...

Chapter 6

Conclusions

This Master's Thesis presented a proposal and implementation of automated acceptance testing environment for payment terminal software and addressed the theories and problems related to the topic. Presented AAT environment was joint combination of open source hardware and software and was formed by the requirements of Eficode Oy's customer.

Literature review of this Master's Thesis addressed the four problem statements introduced in the beginning of this Master's Thesis.

This Master's Thesis also lays a promise of how commonly and inexpensively available components can be used in relatively demanding applications. By combining different open source products, highly adaptive AAT environment was created for the needs of automated acceptance testing of payment terminal software.

Bibliography

James Bach. Test automation snake oil. *Windows Tech Journal*, 10, 1996.

BCN3D-Moveo. URL `https://github.com/BCN3D/BCN3D-Moveo` Accessed 5.9.2016, n.d.

Bart Broekman and Edwin Notenboom. *Testing embedded software*. Pearson Education, 2003.

Cucumber. URL `https://cucumber.io/` Accessed 7.9.2016, n.d.

Christof Ebert and Capers Jones. Embedded software: Facts, figures, and future. *Computer*, (4):42–52, 2009.

Gherkin. URL `https://github.com/cucumber/cucumber/wiki/Gherkin` Accessed 7.9.2016, n.d.

GRBL. URL `https://github.com/grbl/grbl` Accessed 15.7.2016, n.d.

grblShield. URL `https://www.synthetos.com/project/grblshield/` Accessed 1.9.2016, n.d.

Borge Haugset and Geir Kjetil Hanssen. Automated acceptance testing: A literature review and an industrial case study. In *Agile, 2008. AGILE'08. Conference*, pages 27–38. IEEE, 2008.

Dorota Huizinga and Adam Kolawa. *Automated defect prevention: best practices in software management*. John Wiley & Sons, 2007.

JUnit. URL `http://junit.org/` Accessed 7.9.2016, n.d.

Mohd Ehmer Khan and Farmeena Khan. A comparative study of white box, black box and grey box testing techniques. *Int. J. Adv. Comput. Sci. Appl*, 3(6), 2012.

Charles Lowell and Jeremy Stell-Smith. Successful automation of gui driven acceptance testing. In *Extreme programming and agile processes in software engineering*, pages 331–333. Springer, 2003.

R.C. Martin. *Clean Code: A Handbook of Agile Software Craftsmanship*. Robert C. Martin series. Prentice Hall, 2009. ISBN 9780132350884. URL `https://books.google.com/books?id=hjEFCAAAQBAJ`.

Lorraine Morgan and Patrick Finnegan. Benefits and drawbacks of open source software: an exploratory study of secondary software firms. In *Open Source Development, Adoption and Innovation*, pages 307–312. Springer, 2007.

D.J. Mosley and B.A. Posey. *Just Enough Software Test Automation*. Just enough series. Prentice Hall PTR, 2002. ISBN 9780130084682. URL `https://books.google.com/books?id=PEBvfWESIt4C`.

G.J. Myers, C. Sandler, and T. Badgett. *The Art of Software Testing*. IT-Pro collection. Wiley, 2011. ISBN 9781118133156. URL `https://books.google.fi/books?id=GjyEFPkMCwcC`.

Nokia Solutions and Networks. Robot Framework User Guide, 2015. `http://robotframework.org/robotframework/latest/RobotFrameworkUserGuide.html/`. Accessed 6.5.2016.

OpenCV. URL `http://opencv.org/` Accessed 18.7.2016, n.d.

James W Paulson, Giancarlo Succi, and Armin Eberlein. An empirical study of open-source and closed-source software products. *Software Engineering, IEEE Transactions on*, 30(4):246–256, 2004.

Picamera. URL http://picamera.readthedocs.io/en/release-1.12/ Accessed 7.9.2016, n.d.

R.S. Pressman. *Software Engineering: A Practitioner's Approach*. McGraw-Hill higher education. Boston, 2005. ISBN 9780073019338. URL https://books.google.com/books?id=bL7QZHtWvaUC.

pySerial. URL http://pythonhosted.org/pyserial/ Accessed 4.5.2016, n.d.

Pytesseract. URL https://pypi.python.org/pypi/pytesseract Accessed 4.5.2016, n.d.

Python. URL https://www.python.org/ Accessed 7.9.2016, n.d.

Rudolf Ramler, Werner Putschögl, and Dietmar Winkler. Automated testing of industrial automation software: Practical receipts and lessons learned. In *Proceedings of the 1st International Workshop on Modern Software Engineering Methods for Industrial Automation*, MoSEMInA 2014, pages 7–16, New York, NY, USA, 2014. ACM. ISBN 978-1-4503-2851-7. doi: 10.1145/2593783.2593788. URL http://doi.acm.org/10.1145/2593783.2593788.

Raspberry Pi 2. URL https://www.raspberrypi.org/products/raspberry-pi-2-model-b/ Accessed 1.6.2016, n.d.

Raspberry Pi Camera Module. URL https://www.raspberrypi.org/products/camera-module/ Accessed 1.6.2016, n.d.

Raspbian. URL https://www.raspberrypi.org/downloads/raspbian/ Accessed 4.5.2016, n.d.

Robot Framework. URL http://robotframework.org/ Accessed 1.6.2016, n.d.

Robot Framework CNC Library. URL https://github.com/Eficode/robotframework-cnclibrary Accessed 1.8.2016, n.d.

ShapeOko 2. URL `http://www.shapeoko.com/wiki/index.php/ShapeOko_2` Accessed 1.6.2016, n.d.

ShapeOko 2 Github. URL `https://github.com/shapeoko/Shapeoko_2` Accessed 15.7.2016, n.d.

I. Sommerville. *Software Engineering*. International Computer Science Series. Pearson, 2011. ISBN 9780137053469. URL `https://books.google.fi/books?id=l0egcQAACAAJ`.

Stanislav Stresnjak and Zeljko Hocenski. Usage of robot framework in automation of functional test regression. In *ICSEA 2011 The Sixth International Conference on Software Engineering Advances*, 2011.

Tesseract OCR. URL `https://github.com/tesseract-ocr/tesseract` Accessed 4.5.2016, n.d.

Appendix A

First appendix

Smoke 20 Valid Pin Test Log

Generated
20150424 12:41:41 GMT 00:00

Test Statistics

Total Statistics	Total	Pass	Fail	Elapsed	Pass / Fail
Critical Tests	1	0	1	00:01:45	
All Tests	1	0	1	00:01:45	

Statistics by Tag	Total	Pass	Fail	Elapsed	Pass / Fail
No Tags					

Statistics by Suite	Total	Pass	Fail	Elapsed	Pass / Fail
Smoke 20 Valid Pin	1	0	1	00:01:48	

Test Execution Log

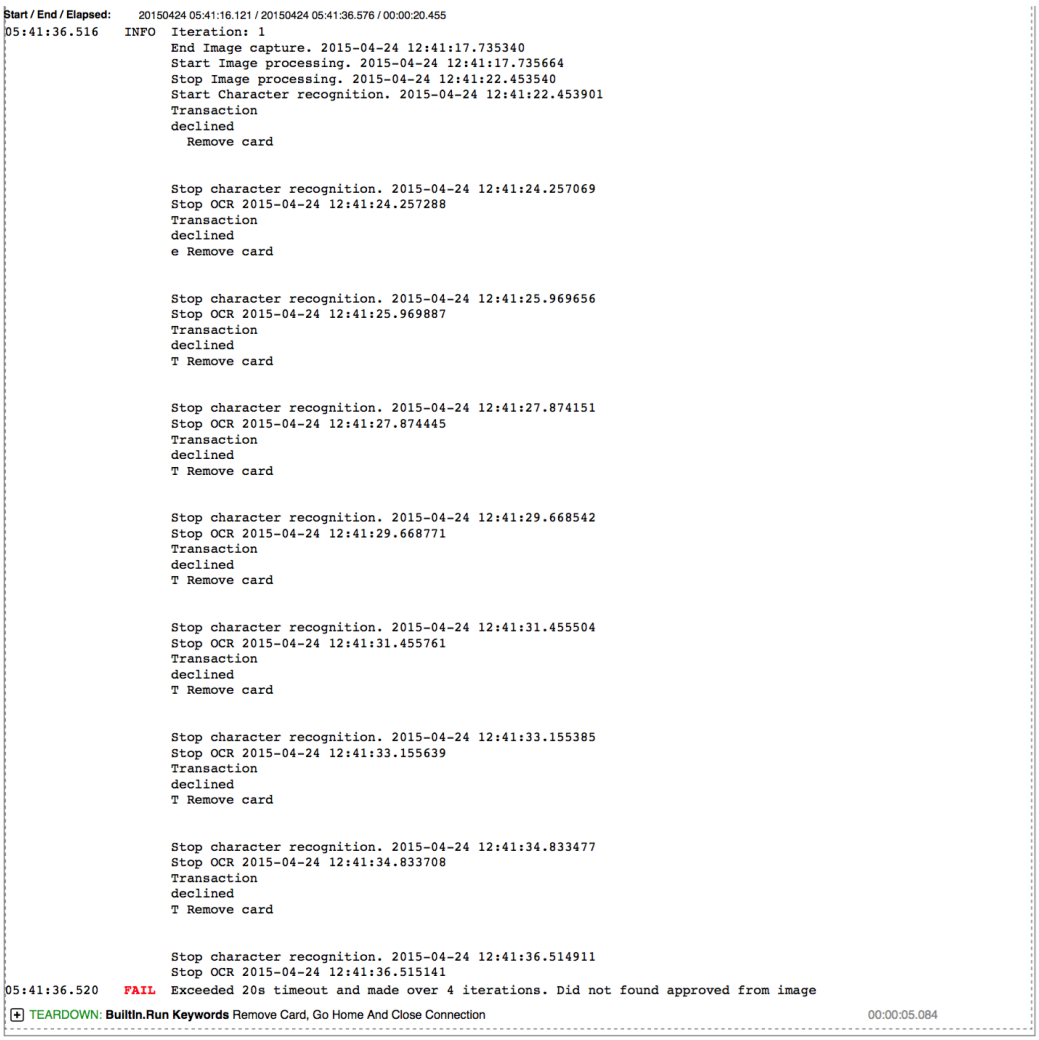
TEST SUITE: Smoke 20 Valid Pin 00:01:48.287

Full Name: Smoke 20 Valid Pin
Documentation: A test suite for testing the machine movement and OCR
Source: /home/pi/NETS/suites/smoke_20_valid_pin.txt
Start / End / Elapsed: 20150424 05:39:53.389 / 20150424 05:41:41.676 / 00:01:48.287
Status: 1 critical test, 0 passed, 1 failed
1 test total, 0 passed, 1 failed

TEST CASE: Test Run For Device 1 00:01:44.989

Full Name: Smoke 20 Valid Pin.Test Run For Device 1
Start / End / Elapsed: 20150424 05:39:56.680 / 20150424 05:41:41.669 / 00:01:44.989
Status: FAIL (critical)
Message: Exceeded 20s timeout and made over 4 iterations. Did not found approved from image

KEYWORD: **resource.Set Home And Initialize** 1 00:00:08.414
KEYWORD: **StreamLibrary.Press** red 00:00:05.189
KEYWORD: **resource.Screen Should Contain Text** Terminal ready 00:00:08.767
KEYWORD: **StreamLibrary.Press** 2, 0, 0 00:00:11.207
KEYWORD: **resource.Screen Should Contain Text** 2,00 00:00:09.234
KEYWORD: **StreamLibrary.Press** green 00:00:04.311
KEYWORD: **resource.Screen Should Contain Text** card 00:00:09.515
KEYWORD: **resource.Insert Card** 00:00:05.017
KEYWORD: **StreamLibrary.Press** 1, 2, 3, 4 00:00:12.735
KEYWORD: **StreamLibrary.Press** green 00:00:04.095
KEYWORD: resource.Screen Should Contain Text approved 00:00:21.373
Start / End / Elapsed: 20150424 05:41:15.206 / 20150424 05:41:36.579 / 00:00:21.373
KEYWORD: **StreamLibrary.Go To Camera** 00:00:00.905
KEYWORD: OCRLibrary.OCR Find From Image ${Text}, ${IMAGE_PATH} 00:00:20.455



```
Start / End / Elapsed:     20150424 05:41:16.121 / 20150424 05:41:36.576 / 00:00:20.455
05:41:36.516    INFO  Iteration: 1
                      End Image capture. 2015-04-24 12:41:17.735340
                      Start Image processing. 2015-04-24 12:41:17.735664
                      Stop Image processing. 2015-04-24 12:41:22.453540
                      Start Character recognition. 2015-04-24 12:41:22.453901
                      Transaction
                      declined
                        Remove card


                      Stop character recognition. 2015-04-24 12:41:24.257069
                      Stop OCR 2015-04-24 12:41:24.257288
                      Transaction
                      declined
                      e Remove card


                      Stop character recognition. 2015-04-24 12:41:25.969656
                      Stop OCR 2015-04-24 12:41:25.969887
                      Transaction
                      declined
                      T Remove card


                      Stop character recognition. 2015-04-24 12:41:27.874151
                      Stop OCR 2015-04-24 12:41:27.874445
                      Transaction
                      declined
                      T Remove card


                      Stop character recognition. 2015-04-24 12:41:29.668542
                      Stop OCR 2015-04-24 12:41:29.668771
                      Transaction
                      declined
                      T Remove card


                      Stop character recognition. 2015-04-24 12:41:31.455504
                      Stop OCR 2015-04-24 12:41:31.455761
                      Transaction
                      declined
                      T Remove card


                      Stop character recognition. 2015-04-24 12:41:33.155385
                      Stop OCR 2015-04-24 12:41:33.155639
                      Transaction
                      declined
                      T Remove card


                      Stop character recognition. 2015-04-24 12:41:34.833477
                      Stop OCR 2015-04-24 12:41:34.833708
                      Transaction
                      declined
                      T Remove card


                      Stop character recognition. 2015-04-24 12:41:36.514911
                      Stop OCR 2015-04-24 12:41:36.515141
05:41:36.520    FAIL  Exceeded 20s timeout and made over 4 iterations. Did not found approved from image
TEARDOWN: BuiltIn.Run Keywords Remove Card, Go Home And Close Connection                    00:00:05.084
```