KTH Stockholm

Multi-tool support for multi touch

KTH Stockholm Zhijia Wang, Karsten Becker Group 192

Abstract

In this report we are investigating the usage of Radio Frequency Identification (RFID) for object identification on multi-touch surfaces. One of the currently most used technologies are fiducial markers which use the optical system to detect and identify objects. However the object needs to touch the surface. With RFID the optical fingerprint of the object does not matter anymore because the identification is done wirelessly. However the location is no longer known anymore. This report provides a solution for this problem and discusses its advantages and disadvantages compared to fiducial markers. To verify that it can be used in reality we built a prototype of a system that uses RFID.

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1 Introduction

1.1 Background

Nowadays, the single-touch screen technology has become a very popular way for humans to interact with machines. It can be found in many smart phones, PDAs and other tools that have a comparably big screen. Multi-touch (MT) consists of a touch screen (screen, table, wall, etc.) or touchpad, as well as software that recognizes multiple simultaneous touch points, as opposed to single-touch technologies that only recognizes one touch point. Recognizing multiple touches at the same time is achieved through a variety of means, including but not limited to: heat, finger pressure, high frame-capture-rate cameras, infrared light, optic capture, tuned electromagnetic induction, ultrasonic receivers, transducer microphones, laser rangefinders, and shadow [Penncock 2008].

Technician and professionals are developing different MT applications based on different ways[Han 2005][Buxton 2007]. Microsoft surface is one of those. It allows the interaction of multiple people on the same projection surface. Even larger MT walls have been introduced [Brown 2008]. However one of their problems is the identification of hands or objects. Microsofts solution for identification is to use fiducial makers (FM). FM are little structures that create distinct patterns on the surface when it touches it. However they require the objects, for example mobile phones, to have those markers applied and the marker needs to touch the surface.

1.2 Research Problem

In our opinion fiducial makers are not an ideal solution. For example it is not possible to identify the same hand that is working on different parts of the surface. Our project thus uses Radio Frequency Identification (RFID)[Dobkin 2007] as a complementarity technique to identify objects. The tags in RFID system are small and inexpensive enough to put them into many objects such as gloves or pens[Hornyak 2008]. We also believe that those tags will be available in mobile phones quite soon.

1.3 Research Goal

RFID is a technology that is made for identification without an optical path. With FM two information are captured at the same time - the identification and the position. RFID is designed to provide the first one, identification. The location can only be restricted to an area as opposed to a point. Our goal is to show that it can be used anyway.

1.4 Methodology

At first we explore the possibilities and requirements for object identification with RFID. We then build a small prototype that shows the feasibility of our goal. We designed a suite of test-cases to compare our technology with FM. At last we explore if the obtained results can be extrapolated to a real-world usage.

1.5 Limitations

With the paper of Jeff Han [Han 2005] multi-touch was made popular for a large group of do-it-yourself people. As such there are many forums and websites dedicated to that thematic. On the downside is that not so many scientific publications are available. Also because of time constraints our prototype is very limited in its capabilities. We also do not have the possibility to test the reacTIVision system. So the comparisons are based on the description published in papers.

2 Test cases

The goal of this paper is to show that RFID technology indeed can be used for MT. We verify that this goal has been accomplished by comparing the most vital properties of FM with our system. We identified the following test cases.

2.1 Precision and accuracy of the position of the detected object

FM have the benefit of determining the position and the objects ID at the same time. Our system has to deliver about the same results as FM as this is a very crucial requirement in MT.

2.2 Timing precision for object detection

The identification of the object has to occur within a reasonable amount of time so that the user has the feeling that he really is interacting with the object on the surface.

2.3 Influence of environmental parameters on the object detection

An MT system can be used in very different environments. So the less restrictions are imposed on the environment the more versatile is a system. FM use the optical path for identification and thus have requirements on stray light in the environment.

2.4 Influence of the detection methodology on the visual projection

The visual projection is the image the user sees on the surface. An identification methodology that interferes with this projection can decrease the usability or user acceptance of the whole system.

2.5 Detection range for objects

A detection range that does not rely on the user touching the surface can create additional benefits and applications. For example for gesture detection. However the range should also not be too far to catch up on everything that is not intended to be used with the system.

2.6 Number of identifiable objects

With a higher number of identifiable objects the user has a greater freedom to use many kinds of objects. For example a pen could be permanently assigned to a person even with a large user base.

2.7 Constraints on the object to be identified

In an ideal world every object would be usable without special modifications. Due to the complex nature of objects recognizing them is very hard for a computer. However the lower the constraints are on the objects the more versatile is a system.

3 Object identification and location

3.1 Overview of object recognition on MT surfaces

Object recognition in computer vision is the task of finding a given object in an image or video sequence. In our MT application we want to recognize different objects such as a pen, an eraser or a pen with a different color. FM simplify computerized image processing by providing an easy-to-track feature in the image. This allows applications such as motion capture to detect movements and orientation of the marked subject [Kaltenbrunner 2005]. As no other hardware than the camera is required, FM based object recognition is very popular. Especially since one popular tracking software reacTIVision is freely available.

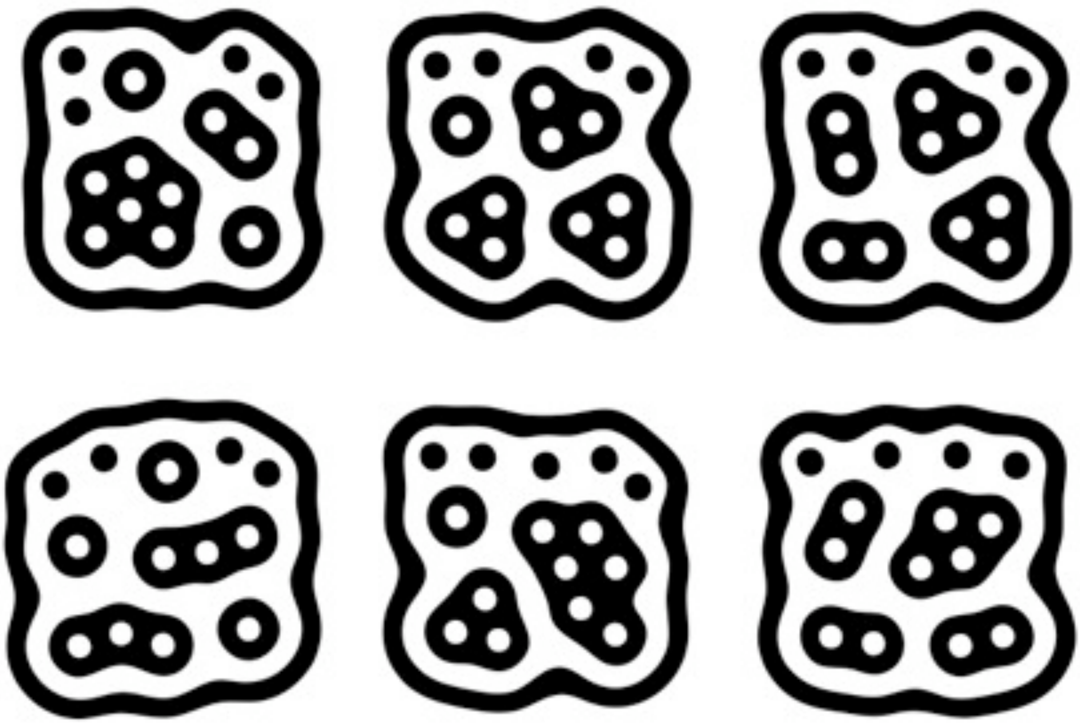

Figure 1: Fiducial makers as used by the reacTIVision System

3.1.1 Advantages of FM

With their distinct patterns FM allow the identification of many different objects. Also the location is captured in the same moment as the identification which is very advantageous for the usage in MT applications. On the hardware side only a camera is needed which makes them quite cheap as the camera is needed for tracking the fingers anyway [Han 2005].

3.1.2 Disadvantages of FM

Depending on the used MT-technology they can be quite hard to produce. In some simple cases it is enough to just print them, in others they need to be created as reliefs. Another problem is that the optical recognition is totally depending on the illumination of the marker, which might depend on the pressure that is used or optical obstacles.

3.2 Object identification with RFID

RFID is designed as a replacement for the well known barcode found on many products. It replaces the disadvantage of barcodes to require a line of sight with the problem of localization. That means the location of the object to be identified with RFID is not well known. However it can be restricted to an area within the reading range. Due to the physics of electromagnetic waves this area can vary substantially [Dobkin 2007 page 70].

3.2.1 RFID radio technology

RFID requires two components. A reader, which is a piece of hardware attached to an antenna on one side and the computer on the other side. The tag is a small antenna with a very small IC attached to it. The IC contains the ID that can be read by the Reader.

There are multiple kind of tags. Fully passive, semi passive and active ones. Fully passive ones do not have a power supply and thus require to be much closer to the reader antenna than for example semi passive ones. Those have a small battery which is used for sending when an incoming request is detected. Active ones have the longest range and are fully battery powered. They also can send on their own without an initiated request [Dobkin 2007 page 35].

Another important parameter for RFID is the way of transmission. There are inductively coupled tags and radiative coupled ones.

Inductively coupled tags work by modulating the current inducted from a sender. The sender then can sense that some inducting occurred. The reading range of these tags is limited to a few centimeters because the energy of the signal is falling away as the cube of the distance [Dobkin 2007 page 25].

Radiatively coupled tags work by backscattering the signal from the sender. The sender receives the backscattered signal. The reading range is much larger than with inductive coupling as the signal is falling with the square of the distance instead of the cube [Dobkin 2007 page 26].

3.2.2 Choice of radio technology

As we showed earlier RFID does not provide an exact location, but rather an area for tag. However knowing the location is crucial for our application of RFID. We thus have chosen to use inductively coupled passive tags with 13.56 MHz. They have the advantage of having a short reading range (around 5 cm) and because of the low frequency penetrate human body parts much better [Dobkin 2007 page 30].

4 System design

4.1 Hardware

In our lab we have all requisites to create our own antennas. We also have TI-S6350 reader module which operates at 13.56 MHz with inductive coupling. The idea to use RFID for MT is that we partition the screen in multiple segments. So that when a tag is detected in one segment we can conclude that it is in this segment or in between two when detected in two adjacent segments. It is obvious that decreasing the area of a segment and thus using more segments would increase the resolution. For our prototype we decided to create two antennas because they take a long time to build and tune. With those two antennas we can test if there are interference problems when they are close to each other.

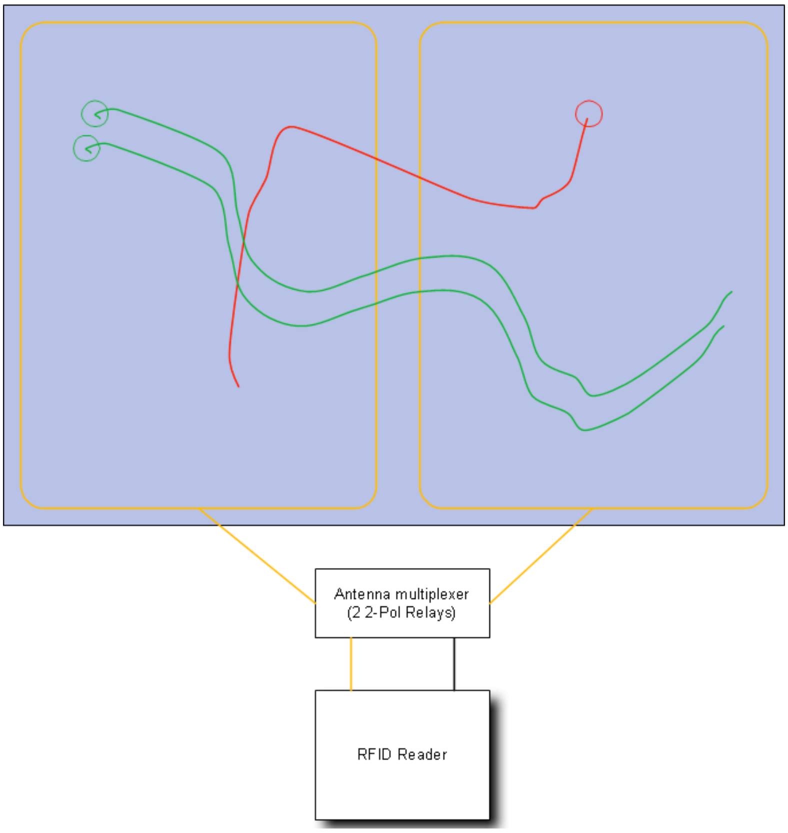

Figure 2: Multi-touch area (light purple) segmented with 2 antennas (orange).

4.1.1 Multi-touch

Our, unfortunately very small, MT surface works with the frustrated total internal reflection (FTIR) as described by Jeff Han [Han 2005]. However as the antennas are distributed over the MT surface they obstruct the optical path as shown in figure 3. From this figure it is obvious that our wire should be as small as possible. However we never created an antenna with such a small wire before. From the formulas we found there does not seem to be any problem to use a wire as small as 0.1mm.

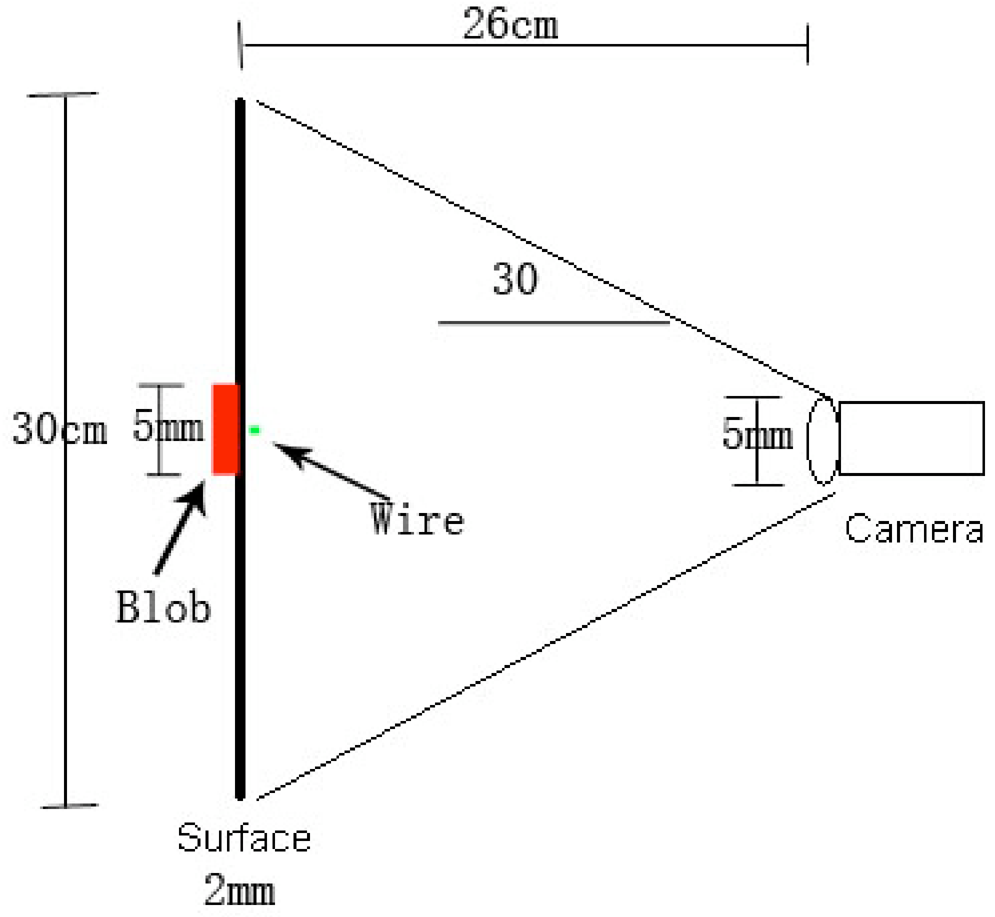

Figure 3: The optical system of our MT surface with the antenna wire

4.1.2 Antenna

The possibility to design an antenna with a 0.1 mm diameter wire is determined by the fact whether the resonance capacitor is available to coordinate with the antenna's inductance. According to the TI HF antenna design note [TI 2003]:

$$L_{uH} = Side \times 0.008[ln(\frac{Side \times 1.414}{2 \times Diameter}) + 0.379] \tag{1}$$

For our surface, the size is a 15 cm circle antenna with 0.1 mm diameter copper wire.

$$L_{uH} = 15 \times 0.008[ln(\frac{15 \times 1.414}{2 \times 0.01}) + 0.379] \tag{1}$$

$$L_{uH} = 0.88\mu H \tag{2}$$

Our measurements confirmed the calculated inductance with 0.86 μH. To tune the antenna to resonate on 13.56 MHz a capacitor is needed. If this value is unreasonable it means the antenna cannot be built.

$$C_{RES} = \frac{1}{w^2 L} \tag{1}$$

$$w = 2 \times 3.14 \times f \tag{2}$$

$$f = 13.56MHz \tag{3}$$

$$C_{RES} = \frac{1}{(2 \times 3.14 \times f)^2 \times L} \tag{4}$$

$$= \frac{1}{(2 \times 3.14 \times 13560000)^2 \times 0.00000088} \tag{5}$$

$$C_{RES} = 1.57 \times 10^{-10}(157pF) \tag{6}$$

From the calculation, we found that the capacitance is 157 pF which is very easy to get. Just parallel a 110pF with a 100pF variable capacitor. To simplify the calibration a 10pF variable capacitor is also needed. With the variable capacitor and the T section position we tuned the antenna to match the impedance of the reader of 50Ω j0. Our measured value was 49Ω j13 and 51Ω j6 for the second antenna. Good enough for the TI reader to detect tags in the distance we required.

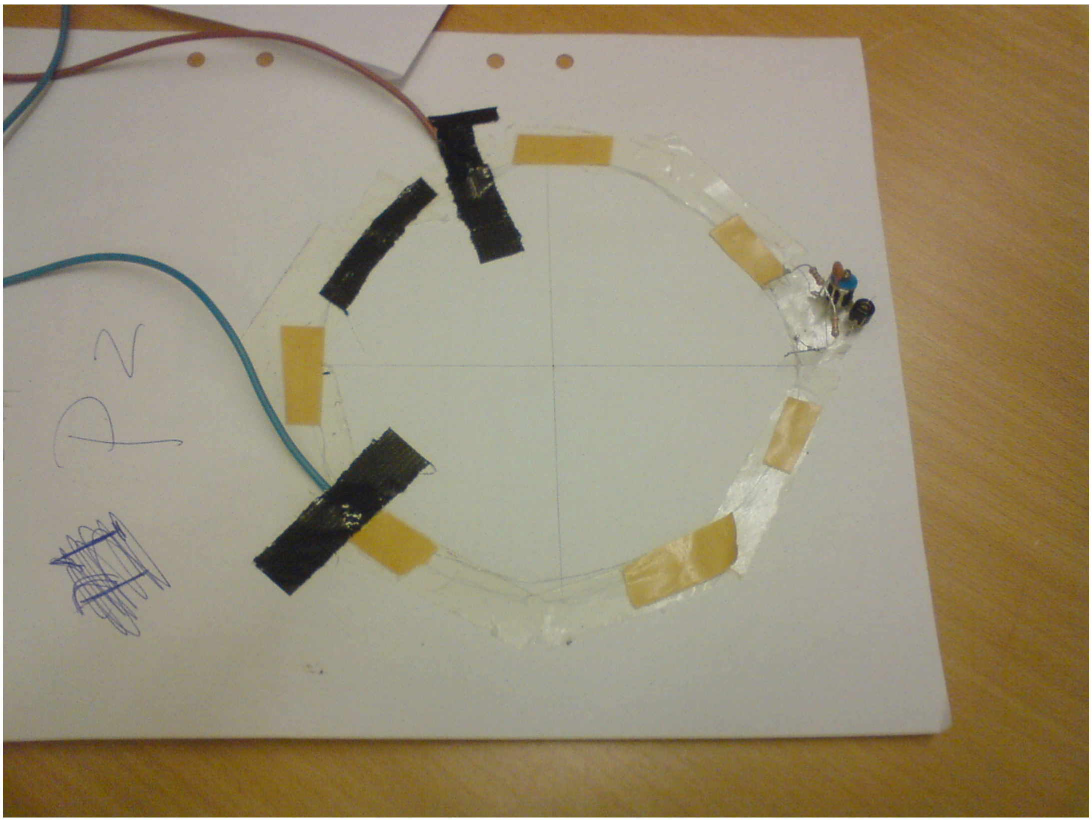

Figure 4: The antenna clued to a piece of paper to support it. On the right side are the capacitors we used for trimming and some resistor to drop the Q.

4.1.3 Using multiple antennas

In our prototype we are using two antennas. Each antenna equals a segment on the MT surface. So we need to know which antenna detected the tag. There are two ways to solve that problem. Use multiple readers or switch between antennas.

While the first solution is feasible for two antennas it becomes quite unreasonable for 25. It also very expensive to have so many readers. The second solution is to switch between the antennas which is what we did.

The easiest way to do that is to use a 2 Single Pole Single Throw relay. This is connected to one of the 2 pin outs of the reader module.

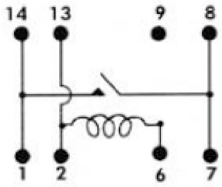

Figure 5: Pinout of the relay we used

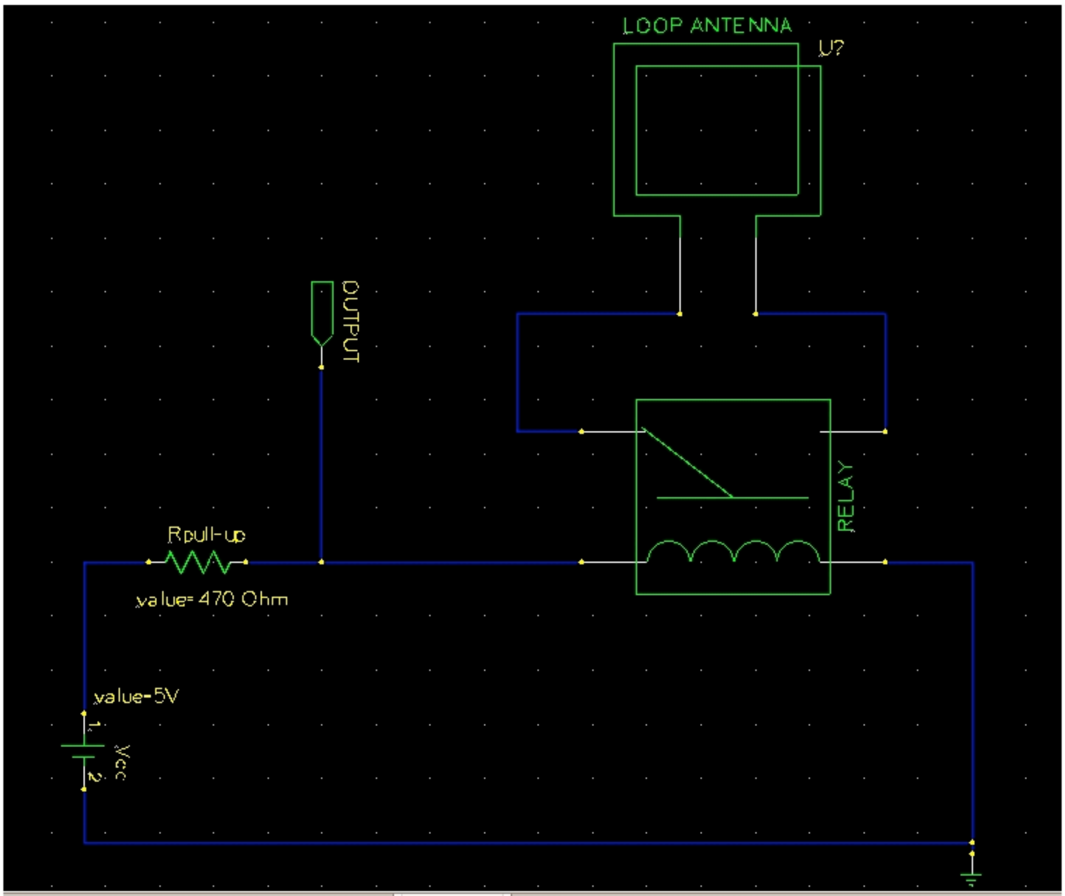

Figure 6: Schematic of the switching circuit for 1 antenna. We used 2 out pins of the reader.

4.1.4 Conclusion hardware

With the built hardware we were able to detect the tag. We also were able to tell which antenna detected the tag because they were not switched on at the same time. The switching rate was limited by the speed of the serial connection (56.000 kbs) and the length of the command (10-18 bytes). Having the antennas side by side was no problem at all. A probable explanation is that the metal part is by far too small to provide any shielding or parasitic effect.

4.2 Location and RFID

While we could show that we can distinguish the segment of the object, this is not very precise. However we have multiple sources of information. When a tagged object is used on an MT surface it creates a blob, a bright spot that is detected by the multi-touch software. This blob is tracked by the software, in our case the touchlib library. So when a tagged object comes close to the surface the tag is detected first. The blob should appear shortly after that in the segment covered by the antenna.

4.2.1 Required software algorithm

As a proof of concept software a simple sketching software was written. The software associates a blob with an ID retrieved from the reader and associates it with a blob as shown in figure 7.

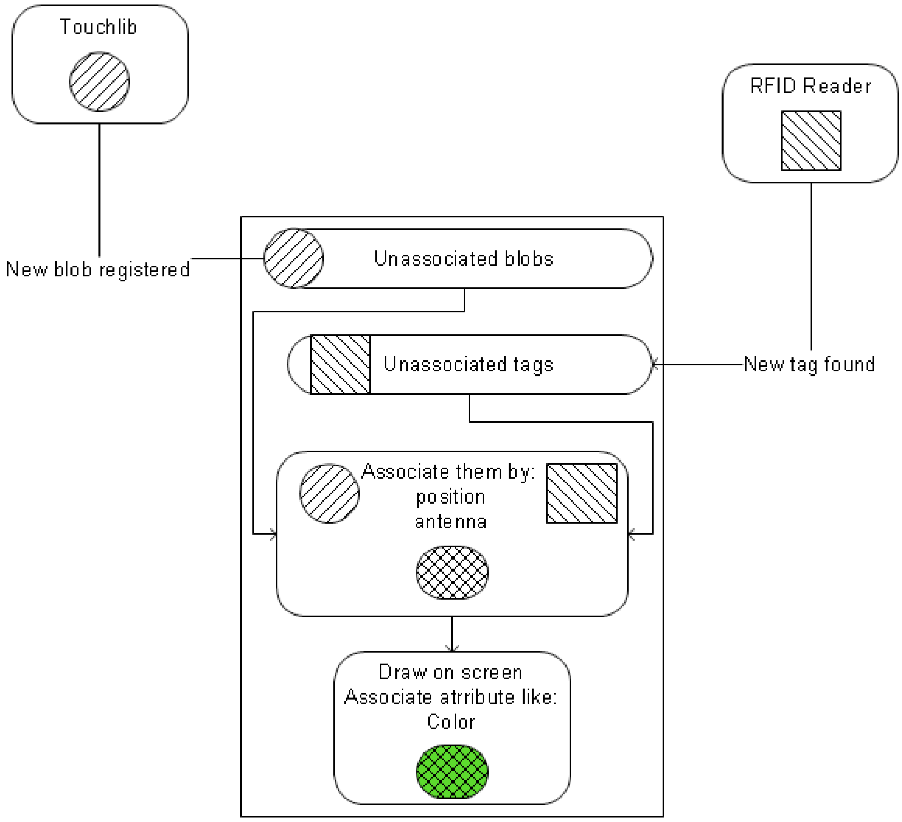

Figure 7: Algorithm used by the software

The software works really well and shows the properties as shown in Figure 2. Once a blob is associated with a tag it keeps its color even when crossing segment boundaries.

5 Test case results

In chapter 2 we specified 7 test-cases that can demonstrate that RFID can be used for object identification in MT applications. Here are the results that we found during the evaluation.

5.1 Precision and accuracy of the position of the detected object

For FM the precision and accuracy largely depends on the camera, the software algorithm and the image quality. In most cases the position can be determined with 1 pixel accuracy or even less. This is due to the fact that the size and geometry is well known and the features are designed to be easy to extract and to identify.

In our system the position is detected by the fusion of multiple sensor events. The temporal and spatial distance of the object creating the blob and the information about the segment of the object is fused to a coherent representation. As such the resolution is mostly dependent on the quality of the MT system for detecting the blob. However it is also easy to fool by creating multiple blobs in the same segment at the same time. It is arguable if this is a feature or a bug. For example when the object to be identified is a hand it makes sense that all fingers touching the surface are assigned to the same object (hand). When multiple pens are touching the surface they should be detected as distinct objects. This problem can be addressed by adding more logic. The number of blobs assigned to an object could be stored with its ID. This way the software will assign only the first blob it sees to the pen or in case of a hand up to 5 blobs.

5.2 Timing precision for object detection

An FM can only be detected when a new frame is captured with the camera. It also depends on the processing time needed to extract the features of the image, but most of the times the frames per second of the camera are the dominant factor here.

The detection of the object in our system depends on the scanning speed of the reader. As we used a relay to switch between the two antennas it also depends on the number of antennas. In the case of the reader we used another bottleneck is imposed by the communication speed of the serial port. This restriction does not exist on readers that use USB. Nevertheless in all cases a detection cycle is much faster than most web cameras that are used for the MT. In example most cameras can only capture 15 fps per second, while our reader could poll each antenna 125 times a second. Depending on the definition of object detection one can say that RFID has a higher timing precision. On the other hand it also depends on the fusion with other data to create a high precision position. So it only excels when the fusion is not needed or the other fusion source is quick enough. As a side note; the blob detection can occur by other means than an optical camera for example capacitive.

5.3 Influence of environmental parameters on the object detection

FM are dependent on visual recognition. As such they are dependent on somehow constant light conditions. In [Kaltenbrunner 2005] it is mentioned that there are indeed problems with stray-light and changing light conditions. Pieces of paper or other opaque objects that are laying on the table can partially cover the marker and thus render them completely unidentifiable.

RFID does not depend on optical recognition and thus is immune to stray-lights. Nevertheless the position of the tags antenna relative to the readers antenna is somewhat crucial. This is caused by the fact that the power for the tag needs to be inducted wirelessly. If the angle between those antennas line up the amount of energy is minimal. So with an un-optimized antenna design as we used it there are blind spots especially when the tag is in an unnatural position such as wrapped around the pen. The use of fully-passive tags however is not required and semi-passive tags could be used to increase the reading range where necessary. Also the design of the antenna could certainly be improved to eliminate those dead spots.

5.4 Influence of the detection methodology on the visual projection

FM obviously block at least the required amount of area to transport the ID. So a pen would need to cover more space than the actual tip would require.

This is one of the major disadvantages of our system. It requires antennas which in case of a rear-projection reside in the optical path as seen in figure 3. The solution for this problem is to reduce the diameter of the wire. As shown in section 4.1.2 it is possible to use a wire of any width. For practical reasons we chose 0.1mm. Smaller sizes are possible if they are for example printed on the surface or a machine is manufacturing it. In our practical experiment with a wire of 0.1mm held in front of a compatible surface with a projected image we found that it is an acceptable size. Especially when the quality of the compliant surface is low. On big projections on some projectors there is also a visible grid between each pixel which can hide the wire at all. For reference, a wire 8 times smaller than our wire was used in the very successful Sony Triniton monitors for dampening [Video FAQ 1997]. So the 0.1 mm are not bad and in theory this size could be reduced further. In our case the size of the MT surface is 30*20 cm with a webcam capturing at 320*200 pixel resolution. One pixel equals thus about 1 mm. This means that the wires are only blocking 10% of the light that could be detected which is very reasonable. The touchlib library has functions to remove background noise and as the wires are static, they are included in that [Touchlib 2008].

5.5 Detection range for objects

FM have a very low detection range as the pattern must be visible. While in theory this could be any distance the compliant surface blurs the image captured by the camera. So the quality of the compliant surface heavily influences the detection range. Also the camera that is capturing the picture influences the distance. A higher resolution camera allows a better distinction between patterns. However stray light falling on the marker surface will lower the contrast and thus further decrease the contrast. Unfortunately there is not documentation about this property for Reactivision.

The detection range of RFID heavily depends on the quality of the antenna, the orientation of the tag relative to the readers antenna, the design of the tags antenna and what kind of tag it is. We tried various TI Tag-it tags [TI Tag-it 2005] and the least reading range we had were 3cm in the middle part and up to 5cm above the wire. We also did test by wrapping the tag around a pen and depending on the angle of the pen and the position it was possible to detect it. Unfortunately we do not have semi-passive tags which are very likely to provide a sufficient reading distance for pens. Also the antennas in the tag are not designed to be wrapped. A custom designed antenna might also improve the detection enough. When embedded in the palm, which would simulate a tag implanted in a glove, the detection was much more reliable and worked well enough when the reading range was not exceeded.

5.6 Number of identifiable objects

In FM the ID of the object is stored in an area that must be visible for the camera. Also the information needs to be identifiable by the camera. Thus the amount of information stored to identify a marker is a function of the resolution of the camera and the area used to store that information. In case of the reacTIVision system the marker have a size of 6*6 cm and 624 distinct IDs have been created for a conference. Creating new IDs is not easy as not all generated IDs can fit the required size or don't meet other limitations.

The number of uniquely identifiable tags is only limited by the amount of memory that is available on the tag. Our tags have 2k bits of memory and thus could store wast amounts of unique IDs.

5.7 Constraints on the object to be identified

FM usually require a planar surface, or at least a surface area that is viewable from the camera. This area needs to contain the ID information. So with the number of distinct IDs this area grows. In most cases this area is planar and needs to be at the bottom of the object. Also this planar surface needs to touch the surface.

With RFID there are only little restrictions on the size and shape of the object. Large rectangular objects are easier to create as the can easily contain a big antenna, which improves the detection distance. In our experiments the coin shaped tags worked but had a lower detection range than the rectangular tags. This is caused by the fact that a) the antenna is smaller and b) the antenna is circular and thus some parts will always align with the readers antenna while others will be perpendicular to it. Nevertheless they worked and could be build into a sphere which could be rolled over the surface which would be impossible to do with FM.

6 Conclusions

In this report we have shown that it is possible to use RFID for object identification and tracking on MT surfaces. The resolution can be adjusted by choosing the number of segments and the size of segments. Even a big segment does not make it unusable as other constraints can be used to avoid false associations. The antennas can be constructed in a way that does not have a significant influence on the optical path.

6.1 Future work

Future studies could research how antennas can be added to plexiglas surfaces by the means of mass production. Another research idea would be to use see-through metals for the antenna. Also possible runtime length measurements or field energy analysis for the replies of the tags could be investigated to increase the accuracy of the location. The usage of semi-passive tags, especially in the pen example could be explored and optimized antennas could be tested.

6.2 Upscaling

Unfortunately we did not have the time to build a big MT surface with rear-projection which includes the RFID detection. The results we gained however are very promising. There are 2 interesting usage scenarios. One is a gigantic MT wall such as the one demoed by Jeff Han and described in Scientific American [Brown 2008]. In this scenario a possible usage would be to distinguish between multiple users. A segment could have the width of 20 cm and would cover the whole height. While the area appears to be very big, the chances that the second user is interfering in the same segment is not so high. On the demoed 2.2 m wall this would require only 11 segments. In our prototype we used relays for switching. These are very slow. Also the switching rate was limited by the serial connection speed rather than the reading speed. When a FET is used for switching and a better reader the switching rate could be significantly increased. A typical read rate for an RFID reader is 350 tags per second [Dobkin 2007 page 384]. With the assumption that detecting no tag takes about the same time as detecting an existing tag, with 11 antennas and 1 tag present the antenna could detect this tag around 11 times a second per segment. Also there is no limitation to use multiple readers to decrease the number of segments per antenna if the rate is not high enough.

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