RFID Technology Applied to Students' Backpacks

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Abstract — **This paper presents the deployment of RFID technology for students' backpacks or schoolbags. It will show a new approach on 13,56MHz technology RFID readers, especially by designing an antenna that is able to monitor and identify which RFID tags are in the bag at a given time. Moreover, the paper will also address the development of control software to aid the students in their daily routine.**

Keywords - RFID; Low Power Bluetooth; Magnetic Coupling; Backpack; Schoolbag,Identity tag; Scholar items

I. Introduction

When young children first go to school, they start a long learning journey, not just referring to the subjects they are going to learn there, but also to the social skills they are about to acquire. It is a parent's job to help their children adapt to this new situation in their lives, and that means spending more time preparing everything the child needs, such as snacks and lunch, and helping them with easy tasks such as preparing the schoolbag for the next school day.

This is a particularly tricky task because you want your children to learn how to do this on their own, but you still need to make sure that all the books and supplies needed for the day are inside the bag, and everything that is not needed is out. Therefore, this paper will present an idea and a technological solution to solve this typical problem. We will start with a general description of the idea, followed by the real implementation, results of the tests performed on the system and a small discussion and conclusion in order to evaluate the potential of the idea itself.

II. The Idea

Our idea was to test the possibility of making an easy-to-use system for monitoring the students' backpacks using RFID technology. We planned to build a schoolbag with two or more RFID antennas inside, that would allow a reader, upon request, to see if all the books and supplies needed for the weekday in question were inside the bag. Naturally, all books and supplies would have to be tagged. Our system would then check a database and issue alerts upon finding items missing in the bag or, inversely, when finding items that are not needed inside the bag.

The full system would encompass the bag itself and a terminal for a supervising person (such as a parent or guardian). The terminal would send a request to get the information of what books and supplies were inside via a low power wireless technology, such as 802.14.4 or Low Power Bluetooth, and the bag would then read the tags within it and send back the requested information. The terminal would then compare the information to the database and display either a message to let the person know that everything is okay, or an alert. The following picture shows a possible block diagram of such system:

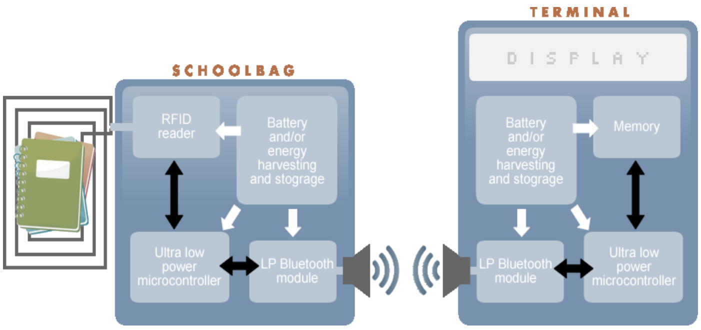

Figure 1. Block diagram of a possible system for checking the correct daily fulfilment of a schollas backpack

However, in order to test the viability of this project, there is no need to implement the full system because it would require making a custom RFID reader from scratch, as well as other pieces of the system. Therefore, we used an existing RFID kit (3ALogics' RFID Reader IC study kit TRH031M's evaluation board) - which allowed us to focus on the study of the RFID antennas and the backpack management software.

Figure 2. 3ALogics' RFID kit - Reader and cards (tags)

The actual prototype system that we used for the tests we performed is presented in Figure 3.

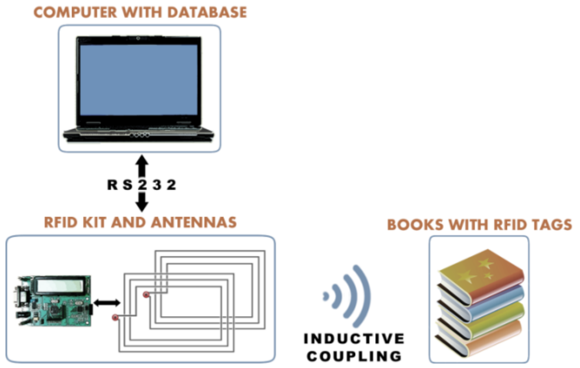

Figure 3. RFID schoolbag prototype system we used in the tests

III. PROJECT AND CALCULATIONS

A. Software

The software needed for these tests consists of an application that allows the user to add books and other school items (pens, pencils, etc.) to a database and then choose which days of the week they are needed for. The same program should also read the bag and tell the user which items are inside it, if they are needed for the specific day, and if there are any items missing.

B. Hardware

Since we are using an RFID kit in this project, the extra hardware needed is solely the antennas. There is already an Electromagnetic Coupling (EMC) filter on the kit, as well as a reception (RX) circuit.

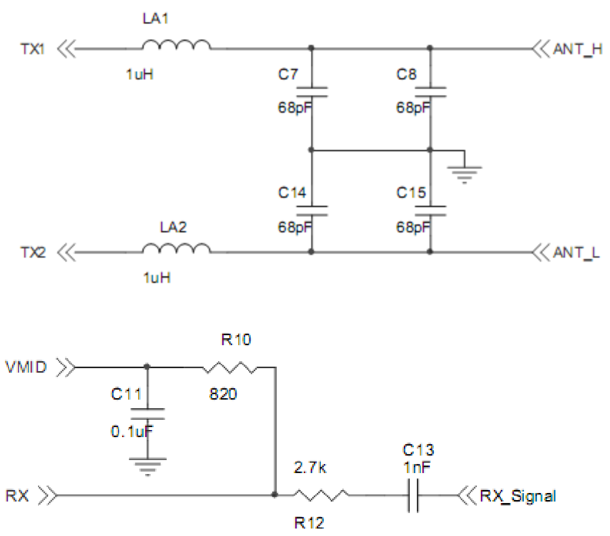

Figure 4. EMC filter and RX circuit of the 3ALogics' RFID study kit (diagrams extracted from [4])

RFID antennas for magnetic coupling are parallel resonant circuits made with a coil (L) and a capacitor (C).

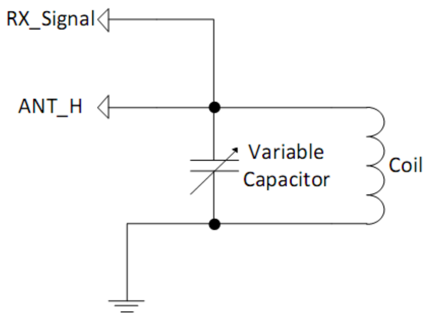

Figure 5. Example of an antenna schematic and how to connect it to the RFID kit

The kit works with a frequency of 13,56 MHz, which should also be the resonant frequency of the antennas:

$$\omega_{res} = \sqrt{\frac{1}{LC}};\ f_{res} = \frac{1}{2\pi\sqrt{LC}}$$
$$13{,}56 \cdot 10^6 = \frac{1}{2 \cdot \pi \cdot \sqrt{L \cdot C}}$$
$$L \cdot C \cong 1{,}38 \cdot 10^{-16} \tag{1}$$

The size of the antennas is very important since the antennas should cover all of the area of the schoolbag. In order to do so, our antennas were made to measure 33,5 × 25 cm, a small amount less than the dimensions of the bag. The inductance formula for a rectangular loop antenna is given by:

$$L_{rect} = N^2 \frac{\mu_0 \cdot \mu_r}{\pi}\left[-2(w+h) + 2\sqrt{h^2+w^2} - h \cdot ln\left(\frac{h+\sqrt{h^2+w^2}}{w}\right) - w \cdot ln\left(\frac{w+\sqrt{h^2+w^2}}{h}\right) + h \cdot ln\left(\frac{2h}{a}\right) + w \cdot ln\left(\frac{2w}{a}\right)\right] \tag{2}$$

where N stands for the number of turns, w for the width, h for the height and a for the radius of the wire.

For a wire with a 2 millimeter diameter, using this formula, we were able to calculate the inductance of different coils with the dimensions specified before - assuming that the relative magnetic permeability (μ_r) equals to one - and the capacitance that needs to be placed in parallel for the kit's resonant frequency. For commodity reasons, we assigned each antenna a letter/name - A, B and C: the results are in Table I:

TABLE I. INDUCTANCE OF DIFFERENT COILS AND RESPECTIVE PARALLEL CAPACITANCE FOR A RESSONANT FREQUENCY OF 13,56 MHZ

Antenna	Number of turns	Inductance	Capacitance
A	5	28,580 µH	5 pF
B	3	10,290 µH	13 pF
C	1	1,143 µH	120 pF

It was also decided that we would use ISO 15693 tags only because this is a standard for vicinity cards which, in theory, can be read from a greater distance than their proximity counterparts, ISO 14443 tags.

IV. IMPLEMENTATION, RESULTS AND ANALYSIS

A. *Software*

The only specific requirement for the software is the ability to communicate with the reader via RS232 in order to fetch the unique identifier of the tags read by the RFID kit.

The software was developed using the .NET Framework.

Its main screen has only four buttons: "Read bag", "Manage items", "Configure" and "Exit". These are enough to meet the requirement.

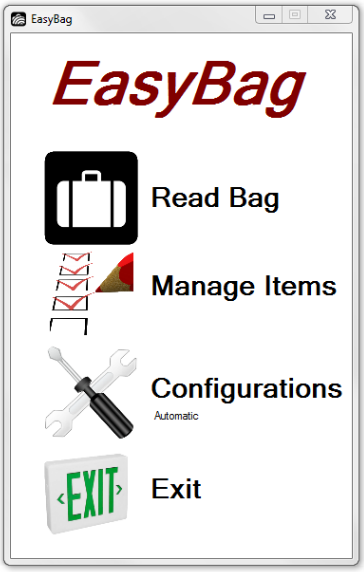

Figure 6. Main screen of the software developed

Figure 7. Antenna A

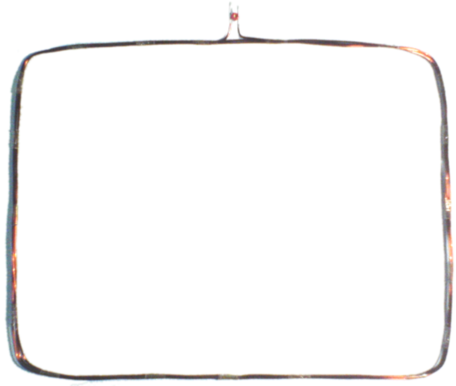

Figure 8. Antenna B

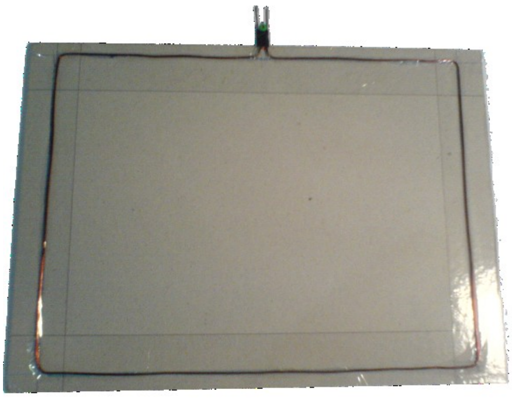

Figure 9. Antenna C

B. *Hardware*

The process of making the antennas was very interesting. It consisted of winding wire and soldering the capacitors to the coils. Since we needed some margin for the parallel capacitance, we chose to use either a variable capacitor or a set of a regular, fixed capacitor in parallel with a variable capacitor (for the single loop antenna). Since Antenna C was more fragile (has less turns), we decided to add a cardboard support for it.

Once having the antennas, we had to tune them. We noticed that the antennas worked best if the parallel capacitance was less than the one calculated, especially when using coils with more than one turn. Most likely, this discrepancy is due to the capacitance of the wires and the fact that the inductance of the actual coils is different from the theoretical one. Because of that, we used a variable capacitor between 4.2pF and 20pF for antennas A and B, and the parallel of a 68pF capacitor with a 5.2 to 30 pF variable capacitor for antenna C. In this last case, we tried to use a 100pF capacitor instead of the 68pF, but with 20% precision we realized that the capacitance was too high.

The first tests made to the antennas were simple “plug and read” tests: we connected each antenna to the reader, one at the time, and tried to read one of the tags. The results of these first tests are in TABLE II.

TABLE II. RESULTS OF THE PRELIMINARY ANTENNA TESTS

Antenna	Observations
A	**Weak reading capabilities:** Almost impossible to read a tag, regardless of its position.
B	**Medium reading capabilities:** Can read tags close to the perimeter of the antenna (near the coil). Small reading range.
C	**Good reading capabilities:** Can read tags anywhere inside the perimeter of the antenna, with a vertical reading range between 10 and 15 cm[1].

Antenna C was, by far, the one that worked best. Therefore, we chose to use single loop antennas for the bag, which was a good choice because they are also lighter.

After performing the simple tests described before, we also performed some more complex tests to antenna C such as reading more than one tag at once and reading tags when they are inside books. The results are presented in TABLE III.

TABLE III. RESULTS OF THE FIRST COMPLEX TESTS PERFORMED ON ANTENNA C

Test description	Results
Reading more than one tag, when they are on the same plane (parallel to the antenna), or at least not directly above one another.	All the tags were read successfully and the reading range did not vary.
Reading more than one tag when they are above one another.	There was some difficulty when reading two or more tags when they were directly above one another and touching each other, but it was possible to read them when they had some empty space in between (approximately 3cm).
Reading one tag inserted in a 2cm thick book (the tag was placed in the middle of the book)	It was possible to read the tag, but the reading range diminished significantly. It was now approximately 5-6 cm.

[1] This range corresponds to the maximum distance between the plane of the antenna and the maximum point where a tag reading is possible.

Due to the problem raised by the last test, it was decided that another coil needed to be made to increase the reading range. Consequently, we made a replica of antenna C to use as a dummy coil in order to concentrate the electromagnetic field and therefore increase the antenna’s range, or at least making it possible to read tags inside books with a range long enough to cover the dimensions of the schoolbag. Then we performed more tests with the dummy coil above the antenna: the results are presented in TABLE IV.

TABLE IV. RESULTS OF THE TESTS USING A DUMMY COIL

Test description	Results
Reading a single tag placed between the dummy coil and the antenna	The reading range increased to approximately 20cm. However, this range depends on the distance between the antenna and the dummy.
Reading a single tag placed inside a book (between the dummy coil and the antenna)	The range was the same as the one verified in the test above (with the same restrictions), probably due to the fact of the flux being more concentrated.
Reading tags inside a pile of stacked books (between the dummy coil and the antenna)	It was possible to read four tags inside four stacked books. As before, the reading capabilities depended on the distance between the antenna and the dummy coil.

In order for the antenna to work well, the distance between the antenna and the tag needs to be approximately 12cm (this is the distance at which tags are best detected). This is the approximate depth of our test bag. Therefore, these results were encouraging and the next step was the placement of the antenna in the bag (cf. Figure 10.

Since both the antenna and dummy coil have a cardboard base, we only had to place the antenna on the back of the bag and the dummy coil on the outer pocket (see Figure 11. and Figure 12.).

Figure 10. Bag where the antennas were placed

Figure 11. Antenna C inside the bag

Figure 12. Dummy coil on the outer pocket of the bag

The last tests performed included the placement of a few books with tags inside the bag, and checking if every book was read. We noticed that in order for the system to work correctly, the dummy coil has to be aligned with the antenna and the tags should not be directly above each other. Once satisfied these requirements, we could always read the books' tags, and therefore detect the presence of the books inside the bag.

V. DISCUSSION

Some of the problems we had with reading the tags inside the bag could be resolved with another fully functional antenna, such as the fact that the distance between the dummy coil and the antenna has to be a predetermined one. However, due to power restrictions of the test board we used we could not attach a second antenna, because it would drain too much current and force the board to shut down. The fact that the tags cannot be aligned to be read properly is a problem to which we have no solution so far, but we think that since this is not a safety-critical application there is no major issue if the system fails to read the bag from time to time and the probability of having the tags aligned within a bag is not very high. Nevertheless, a random placement of tags inside books (e.g. using RFID stickers on the back of the cover) could help to reduce the occurrence of false negatives (undetected tags).

Also, the software developed was merely a testing tool. For a fully commercial solution, there is a need to add security features such as access passwords that would only allow the parent or guardian to add, edit and/or delete items from the database.

VI. CONCLUSION

In conclusion, we believe that a system similar to the one we implemented might be technologically and commercially viable, especially because this is not a safety-critical application, leaving some margin for errors due to false negatives. However, some modifications are needed in order to make the full system more robust, as discussed in the section above, such as making a reader from scratch specifically for this application, as well as professionally-made antennas and a new and better version of the software (at least in terms of security).

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