CHAPTER 22
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INDOOR WIRELESS WAYFINDING SYSTEM FOR WORKERS WITH COGNITIVE IMPAIRMENTS

Part 1: Core System Design and Implementation
Designers: Arpit Mittal, Vimlesh Shukla, Cheng Ling, Muneer Al-Ali
Part 2 Localization Algorithms and Evaluation
Designers: Arpit Mittal, Vimlesh Shukla, Prem Kumar Sivakumar, Liang Huang
Client Coordinator: Derek Finely, Supervisor, Jewish Vocational Services, Southfield, MI
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INTRODUCTION

Indoor wayfinding is a problem for many individuals with cognitive impairments. While there are many applications for indoor location and wayfinding systems, this project will target wayfinding as a work aid for individuals with cognitive impairments. Jewish Vocational Services (JVS) exemplifies an agency that can greatly benefit from this application. JVS is a CARF certified, NISH affiliated, non-profit organization that offers programs and services throughout Metropolitan Detroit. JVS supports individuals, challenged with disabilities, in the workplace and provides on-site, supervision and coaching at community-based employers through their janitorial operations. Job coaches have expressed interest in finding a way to remotely monitor their employees and provide task prompting.

The prototype system is a wireless sensor network (WSN) that uses ten reference nodes, one coordinator node, and a blind node. A reference node is a wireless transceiver at a fixed location. A blind node is a wireless transceiver which moves around an environment containing a collection of reference nodes. A star network infrastructure is used because of its network robustness. If one reference node is removed from the network, the others are not affected. The signal strength as recorded by the blind node is passed back to the PC via the coordinator; a wireless transceiver which connects to the PC through a USB port. A location finding algorithm within the PC calculates the position of the blind node with respect to the reference nodes thereby localizing the blind node in a facility.

The project actually spanned three semesters. The first semester's work was described in "Location

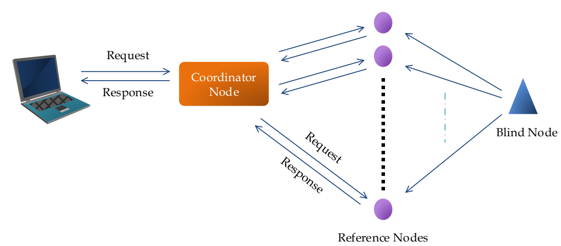

Fig. 22.1. Basic system configuration showing the blind node, reference nodes, coordinator and control PC.

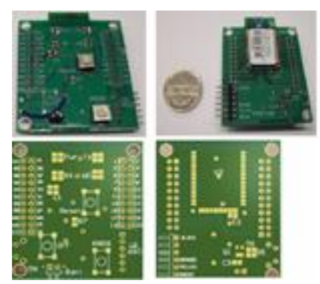

Fig. 22.2. Photo of the prototyped Jennic device both in a 3D model from.

Detection Engine – Part 2 Jennic: JN5139 and JN5148," published in the 2010 Edition of the NSF Projects to Aid Persons with Disabilities. That work designed and built generic transceiver units for the JN5139 and JN5148 and tested their functional capabilities. The resultant system demonstrated viability of the Jennic units to function in wayfinding applications.

In Part 1 of this project, ten new reference nodes were designed, built and tested and several location determination algorithms were implemented and evaluated. The major results from Part 1 indicated that: (1) the communications protocol between the coordinator, the reference nodes and blind node needed to be modified; (2) an accelerometer needed to be added to the blind node so as to more accurately determine movement and the direction of movement, and (3) the current location algorithms were inadequate for the Jennic devices.

In Part 2, an accelerometer was added to the blind node and the communication protocol revised. Revision of the communications protocol required new code for all elements; the coordinator, the blind node and the reference units. A new location detection algorithm was written and tested in both the engineering laboratory and office space at JVS. The new system enables localization of the blind node to within 1 meter.

SUMMARY OF IMPACT

The successful demonstration of the system's ability to localize the blind node to within 1 meter renders the system capable of being used to monitor JVS janitorial workers and thereby enables the supervisor or job coach to provide appropriate prompting and support to a worker via a wireless communication system. JVS's response has been very positive toward the system and they have expressed great interest in the improvements in the software. Our liaison from JVS, Derek Finely, stated, "This service is a great application for indoor wayfinding by providing our job coaches the flexibility of being able to remotely monitor the location of our workers in most facilities".

TECHNICAL DESCRIPTION

All wireless modules, from circuit and schematic design, to printed circuit board (PCB) layout, were custom designed using Altium Designer. Figure 22.2 shows a photo of the prototyped Jennic device both in a 3D model and actual fabrication.

Reference node placement is a critical factor. The Jennic uses a Link Quality Indicator (LQI) signal, derived from the RSSI. As with the RSSI, the observed LQI measurements were inversely proportional to distance moved. The Jennic uses automatic gain control (AGC) which activates when the received signal strength between a reference node and blind node falls below a predetermined threshold, which corresponds to a separation of about 3 meters.

Experimentation clearly demonstrates the onset of the automatic gain feature hence reference nodes which are "far" (greater than 3 meters) from the blind node can be ignored in any location determination algorithm. Also, for separations less than 3 meters, the LQI value is a relatively good indicator of blind node reference separation. These results indicate, that for the given Jennic model, a blind node should always be within 3 meters of 3 reference nodes (3 reference nodes are needed for triangulation algorithms). This constraint should be acceptable for office spaces and the newer Smart Buildings that have high densities of ZigBee modules in the infrastructure.

The localization algorithm has evolved, from methods using signal strength measurements, to a more robust triangulation method. The blind node's onboard accelerometer provides information about its movement and trajectory direction. The algorithm executes in real-time on a MATLAB platform on the control PC.

Tests were conducted at the JVS facility in an office hallway with a length of 30 meters and width of 1.5 meters. The blind node was mounted on a janitorial cart at a height of 1 meter and 10 reference nodes were positioned in a zigzag pattern such that the blind node would always be within 3 meters of at least 3 reference nodes. To measure position accuracy, locations estimated from the algorithm were compared to predefined points on the map. The average estimated location, observed from the trials at the JVS facility, corresponded very well to results from trials performed in the Engineering Building.

The wayfinding system has been successfully demonstrated at the JVS facility. The system met our objectives for providing a solution that is low-cost, portable, easy to use, and robust. From the test results, we have been able to localize a janitorial cart to within 1 meter accuracy. The network can be setup in most office hallways with 3 meter spaced node placement. Total Jennic prototype boards cost about $52/board (15 boards were made), this included the onetime PCB setup charges. The Jennic module alone costs about $23 and an additional $15 for components. The blind node is more expensive because it contains a $20 accelerometer.

DIGITAL HUMAN MODELING: FAB TO RAMSIS INTERFACE

Designers: Muhannad Ghalib, Sam Prasanna Rajkumar James
Client Coordinator: Dr. Gerry Conti, OT, Active Reach and Manipulation (ARM) Clinic, Occupational Therapy Department, Wayne State University
Supervising Professor: Dr. Robert F. Erlandson,
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INTRODUCTION

The Active Reach and Manipulation (ARM) clinic was initiated in Spring 2011, provides sophisticated rehabilitation services to underserved people with stroke and significant movement limitations (SML). The ARM clinic will serve metro Detroit residents with no or limited health care insurance for rehabilitation following a stroke, spinal-cord injury or other neurological injury or disease. The ARM clinic is a collaboration between Occupational Therapy and Biomedical Engineering.

This project pairs the Michigan Rehabilitation Services (MRS) with a cross-disciplinary team of biomedical engineering students and occupational therapy students. They have demonstrated the effectiveness of using a digital human model to design an adjustable computer workstation for a quadriplegic MRS client who wanted to be able to access his computer. The major problem involved placement of a camera for eye-gaze control of the computer's cursor on the monitor. A "visual cone" and "eye-gaze" feature of the digital modeling package helped determine the camera and client placement requirements.

Virtual Ergonomic Assessments (VEA) offers the potential to increase return to work opportunities for adults with significant movement limitations (SML). VEA uses a digital human model (DHM) customized to the client's anthropometric and functional capabilities embedded in a virtual work environment performing job related tasks. The development of VEA will require the integration of computer-aided design, biomechanical movement simulation, and creation of virtual work environments.

Fig. 22.3. Required sensor placements for the FAB system.

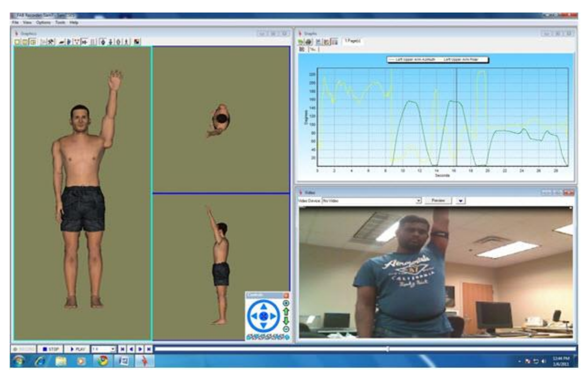

Fig.22.4. FAB display.

SUMMARY OF IMPACT

Dr. Conti, from Occupational Therapy, is using the FAB system to rapidly and accurately measure movement patterns and capabilities of people with SML. The FAB System (Functional Assessment of Biomechanics) is a full body wireless motion capture system based on inertial wireless sensor technology. FAB data is gathered as part of a typical intake procedure and then also to monitor and evaluate client performance. MRS placement specialists agree with our initial experiences that the ability to apply FAB collected data to a digital human model of a client would significantly enhance the VEA process and thereby facilitate the client's efforts to secure employment.

TECHNICAL DESCRIPTION

The Enabling Technologies Laboratory (ETL) uses the Dassault Systems CAD packages CATIA/DELMIA for design and the RAMSIS package from Human Solutions to create digital human models. These packages have very sophisticated digital human modeling (DHM) capabilities which can be used to model individuals with disabilities and SML. The goal of this project was to gather human motion data from a person using the FAB system and then associate that data with a DHM of the same person within the RAMSIS software.

The FAB system uses a different reference coordinate scheme for representing human motion than does the RAMSIS system. There were two major technical challenges: 1) creating an algorithm for translating the FAB collected data into the RAMSIS reference scheme, and 2) associating the required FAB sensor placements on the real human with the representation of these corresponding body segments and joints on the DHM created in RAMSIS.

The real person shown is one of the design team students.

The project goal was satisfied in that data collected via the FAB system was transformed from the FAB reference scheme to the RAMSIS reference scheme

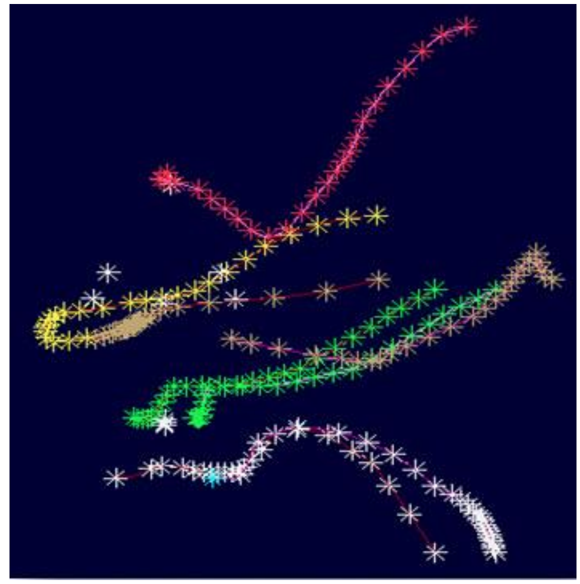

Fig. 22.5. Trajectories for the arm movements from the student in Fig. 22.4.

and the sensor placements of the FAB were placed on the corresponding DHM positions so as to observe the recorded movement patterns. Figure 22.5 shows five arm movement trajectories for the student shown in Figure 22.4.

The current implementation demonstrates the feasibility of the approach. However, the RAMSIS portion of the coordinate transformation algorithm is too slow for actual use in VEA / DHM workplace analysis for a real person's movement patterns. The next step is to gather the FAB data and associate it in "real" time with the RAMSIS DHM. Such a capability will enable utilization of VEA tools to facilitate workplace accommodations and the selection and evaluation of assistive technology needs for people with SML.

ICF COMPLEX DATA VISUALIZATION

Designer: Bhagyesh Bhandar
Client Coordinator: Dr. Gerry Conti, OT, Active Reach and Manipulation (ARM) Clinic, Occupational Therapy Department, Wayne State University
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INTRODUCTION

The Active Reach and Manipulation (ARM) clinic at Wayne State University provides sophisticated rehabilitation services to underserved people with stroke and significant movement limitations (SML). New therapeutic interventions must demonstrate efficacy before being covered by insurers. The ARM clinic is exploring the use of the World Health Organization's (WHO) International Classification of functioning and Disability (ICF) as a clinical tool for assessing therapeutic efficacy. The goal of this project was to explore the use of dynamic visuals displays as exemplified by "Gapmider" to provide a more intuitive representation of ICF data and thereby demonstrate its utility in a clinical setting (http://www.gapminder.org/).

The ICF has four Major Components: Body Functions, Body Structures, Activities & Participation and the Environmental Factors represented by codes b, s, d and e respectively. These four major components are further divided into a broad classification of chapters which are a part of their respective components. All of these Chapters are represented by integer numbers starting from one up to the number of chapters these components possess. For example, b7 designates Neuromusculoskeletal and movement, b730 muscle power functions, b7301 power of muscles one limb.

Each element of the ICF also has an associated qualifier which provides a way to quantify the functional status of an individual. Qualifiers are used to capture the functional status of an individual at a specific point in time. The qualifiers are from a Likert scale: an impairment, limitation or restriction, is qualified from 1to 4: 0 (0-4%: No problem), 1 (5-24%: Mild problem), 2 (25-49%: Moderate problem), 3 (50-95%: Severe problem) to 4 (96-100%: Complete problem). Quantification of the environmental factors is done in a negative and a positive scale which means to what extent the environmental factor is acting as a barrier or a facilitator. The ICF classification has more than 1,400 categories limiting its use in a clinical setting.

ICF_Code	Cateories	Description	PatientRatings	Date
b110	Consciousness Function	General mental functions of the state of awareness and alertness, including the clarity and continuity of the wakeful state.	1.11	12-31-2010 21:17:00
b114	Orientation functions	General mental functions of knowing and ascertaining one's relation to self, to others, to time and to one's surroundings.	2.51	12-31-2010 21:17:00
b167	Mental functions of language	Specific mental functions of recognizing and using signs, symbols and other components of a language.	0.94	12-31-2010 21:17:00
b730	Muscle power functions	Functions related to the force generated by the contraction of a muscle or muscle groups.	2.54	12-31-2010 21:17:00
s110	Structure of brain		0.74	12-31-2010 21:17:00
d330	Speaking	Producing words, phrases and longer passages in spoken messages with literal and implied meaning, such as expressing a fact or telling a story in oral language.	1.63	12-31-2010 21:17:00
d450	Walking	Moving along a surface on foot, step by step, so that one foot is always on the ground, such as when strolling, sauntering, walking forwards, backwards, or sideways.	4.00	12-31-2010 21:17:00

Fig.22.6. A portion of the brief core set for stroke.

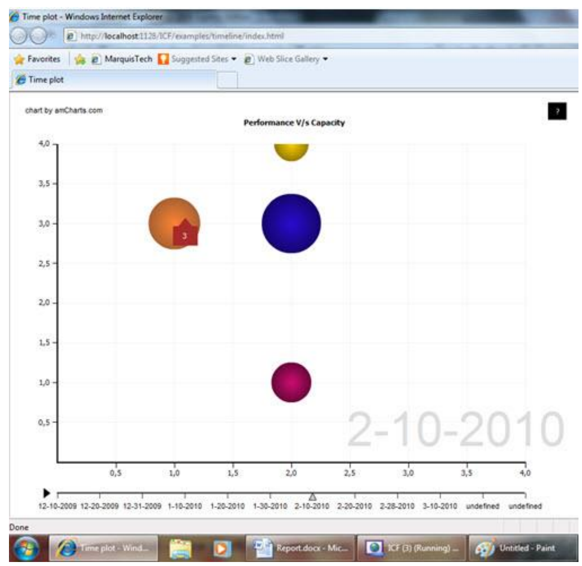

Fig. 22.7 Example of visual display.

SUMMARY OF IMPACT

The preliminary results demonstrated that one can provide dynamic visual displays of the complex ICF qualifier data as it changes over time. Furthermore, the environmental influences of therapy, assistive technology, care-givers, etc. can be explicitly considered.

TECHNICAL DESCRIPTION

Given the ARM clinic's interest in stroke rehabilitation and given the need to more narrowly define the problem, the Brief Core Set for Stroke was selected as the test vehicle. Practitioners are defining "core sets" which are a much smaller number of codes specific to a given condition. Figure 22.6 shows part of the Brief Core Set for Stroke which has 18 items; 6 body functions, 2 body structures, 7 activities and participation, and 3 from environmental factors. The slide bars shown to the right under "Patient Ratings" allows one to provide a fuzzy number value for the ICF qualifiers. This tool was used to create a clinically realistic database of ICF qualifier values collected over time.

Of particular concern were the items from "activity and participation." These items have two parts; capacity and performance. By "capacity," the ICF means the intrinsic capacity to perform an action, as would be assessed in a standard clinical environment without aids or assistance; by "performance," the ICF means the actual performance of an activity in the person's current environment. Qualifier scores were provided using the data entry tool and variety of visualizations were explored.

The slider bar allows the practitioner to enter a qualifier value for an individual. This tool was used to create clinically reasonable data for testing various visualization displays.

Gapminder is a proprietary package for visualization of complex data over time. Google has purchased the rights to the Gapminder algorithms and provides a very simple capability within Google Doc's spread sheet wherein one can insert a "gadget – motion chart" to see the data change over time. Google's Public Data Explorer provides examples of the visual displays. Figure 22.7 shows a simple example.

COOKE SCHOOL SENSORY INTEGRATION TENT AND ACTIVITIES

Designers: Andrew Aneese, Yazan Soofi, Tonya Whitehead, Jenna Batten, Shannon Hogan, Huda Kazak, Sarah Krug, Jillian Woodworth
Client Coordinator: Julie Rohroff, teacher at Cooke School
Supervising Professor: Dr. Robert F. Erlandson,
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INTRODUCTION

The goal of this project was to design and build a sensory integration tent for a classroom at Cooke School. A sensory integration tent is an enclosed space covered with a heavy light blocking material that is large enough to comfortably hold the student. The interior of the tent would allow the student to sit or lay down. Depending on the student's needs, the sensory tent environment can provide alerting or calming activities. Each set of activities requires different items within the sensory tent. The Cooke School students are all severely learning disabled and have cognitive impairments. Their ages range from 14 – 18 with a mental capacity of approximately 2 – 5 years. The tallest student is approximately 6 ft. Cooke is a special education school for children in Northville and surrounding communities. The mission of Cooke School is to prepare students for a productive and meaningful life by increasing communication, vocation, academic, and recreation life skills to be used in school, at home and in the community.

The rationale for the products we are suggesting for the sensory tent, all fall under Sensory Integration Theory. Jean Ayers, the founder of Sensory Integration Theory, defined sensory integration as "The neurological processes that organizes sensation from one's own body and from the environment and makes is possible to use the body effectively within the environment". The sensory tent is meant to improve a student's adaptive responses to sensory input; helping the student become more organized, helping increase attention to tasks, fostering independence, improving performance and decreasing self-stimulatory behavior.

The final design included an interior design plan utilizing the pipe & joint technology CREFORM as the frame or structural support material. The interior

Fig. 22.8. A selection of CREFORM components a pipe & joint agile system's technology.

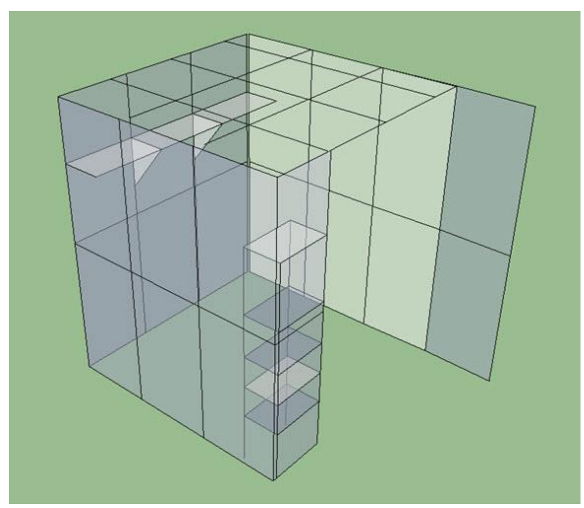

Fig. 22.9 A CAD rendering of the structural frame of the sensory tent. Shelves and storage space are shown in the interior.

design would also include storage layout and placement of power sources. Deliverables also include recommended items for each set of activities. For example, a Ball or Rice Tub is multi-sensory item that will calm or awaken the student's tactile system as well as provide vestibular and proprioceptive input to meet the student's sensory needs. Another example is a Bubble Tube which is visually stimulating and can have a therapeutic mesmerizing effect. Staff can place a mirror behind it for additional effects. Bubble tubes usually fall into two categories, passive (relaxing) and interactive (stimulating). Some tubes have plastic balls, beads and fish added to help develop tracking skills. Specifications for about 30 different activities along with the required materials were delivered to the teachers and staff. Parent volunteers are to sew and construct the covering for the sensory tent.

SUMMARY OF IMPACT

The sensory CREFORM frame was assembled and delivered to the school. A temporary cover was placed over the frame and the tent was stocked with a variety of items. Teachers are using the tent and are pleased with its design. The students are responding to the tent much as the teachers had hoped. The final tent cover will be finished and installed by the start of the Fall semester.

TECHNICAL DESCRIPTION

The frame material is a pipe & joint technology. Figure 22.8 shows a sample of the over 450 CREFORM components available for design and assembly. The components include plastic covered steel pipe in a variety of colors, metal and plastic joints, casters, and hinges. A pipe cutter, Allen wrench and ruler are all the tools needed for assembly. Figure 22.9 is CAD drawing of the tent's structure and Figure 22.10 shows the frame with the temporary cover.

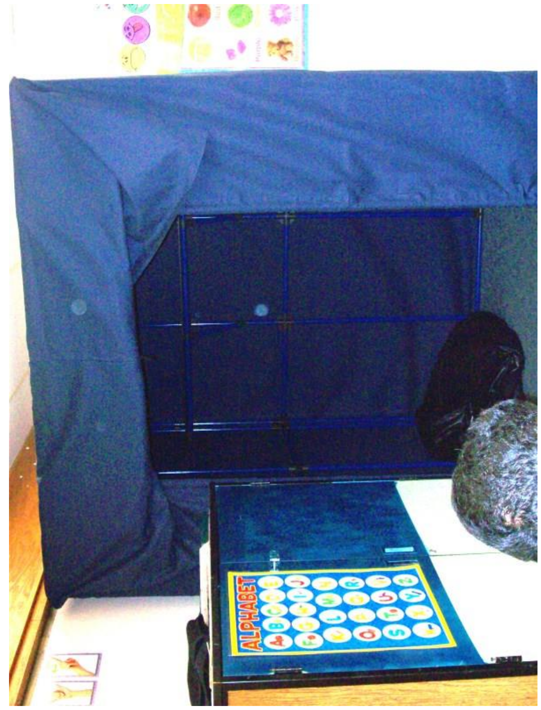

Fig. 22.10.The completed sensory tent with a temporary cover.

RFID TAG SYSTEM FOR PRACTICE DEBIT CARD PROCESS

Designers: Angela Buckley, Prem Sivakumar, Samuel Gibson
Client Coordinator: Dennis McElhone, Special Education Teacher, Visions Unlimited
Supervising Professors: Dr. Robert F. Erlandson, Dr. Donna Case, Santosh Kodimyala
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INTRODUCTION

Visions Unlimited is a post-secondary educational program operated by Farmington Public Schools serving 18 through 26-year-old young adults with developmental and physical disabilities. Emphasis is given to improving the students' life and work skills and, in particular, developing transitional skills required in moving from school to work. Visions Unlimited uses Positive Behavioral Support (PBS) principles to facilitate the educational process. The staff wanted to use a "debit" card like process that uses a point system rather than money, as the positive reward; while concurrently providing their students the opportunity to manage their points to "purchase" items from the school store.

The current system is replacing a previous system that was placed in service in 2008 and, due to computer upgrades and changes at the school, became inoperable in early 2010. Visions Unlimited staff learned a great deal from using the first system and had very specific ideas about the functionality of this new version.

SUMMARY OF IMPACT

The new version has been installed and presented to Vision Unlimited teachers and staff. The introduction was very well received and teachers and staff were eager to have the redesigned system fully operational. The school has shifted to its summer schedule and the new system is receiving minimal use during the summer. Data regarding student

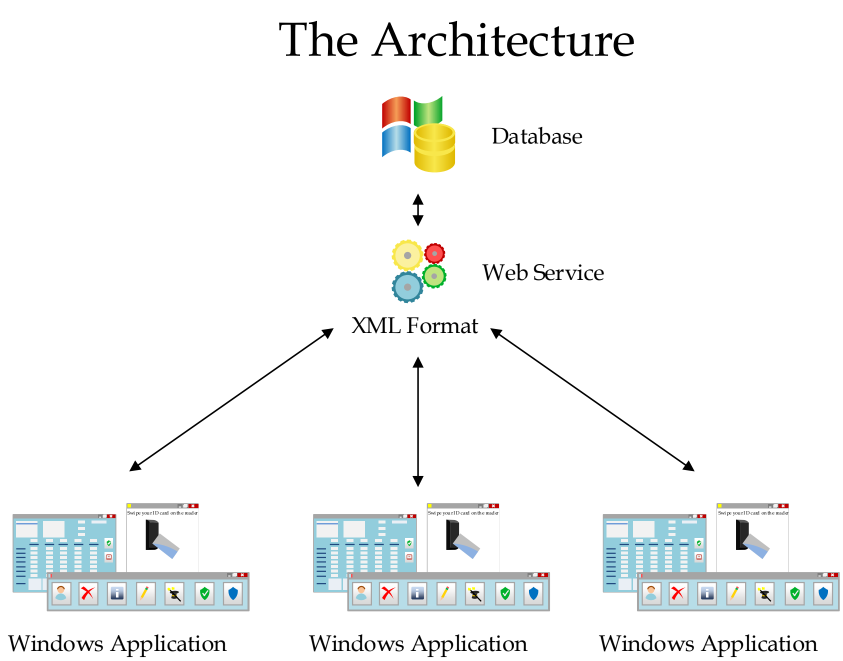

Fig. 22.11. Overview of the "debit" card system. There are seven RFID tag readers spread throughout the school.

points and "purchases" are being transferred from the old system to the system over the summer. A variety of reports can be generated by staff regarding student performance in relation to their respective Individualized Education Plan (IEP) objectives.

TECHNICAL DESCRIPTION

The whole system is built on one SQL database with the option of being deployable even without an SQL database by using a single Microsoft Access file. Web service is a communication method between applications using XML. The communication can also be over a network. In this case, a database server is wrapped around by a web service. The web service acts as a broker between the database and applications running on PC's all over the school network and accessing the database. According to the database, web service is the only application that is accessing the data. Web service acts as a representative for all application entities as one entity.

The Database server is hosted in Microsoft's free hosting service for students through a program called Microsoft DreamSpark (www.dreamspark.com). The database consists of three tables:

1. Buddy Points: This table holds the points scored by the student.

2. Users: This table maintains the details of all the users, both students and teachers.

3. VisionsUnlimitedStore: This table maintains the history of students points usage (how they spend or on what they spend).

There are three applications used by the school to implement the whole system. They are:

1. User Management – This application is used to manage users in the system (Figure 22.12).

Fig. 22.12.The User Management interface screen.

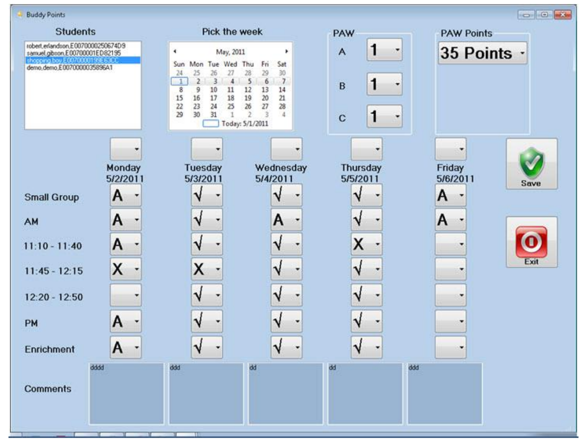

Fig. 22.13. The Buddy Points Management Screen.

2. Staff – This application is used by the teacher to award points to the students (Figure 22.13).

3. School Store – This application runs in the school store to which a card reader will be attached.

Each of the three applications has utilities that guide the user through the correct sequence of actions. Teachers and staff can print a variety of reports that summarize overall usage patterns or target specific behavior that is being monitored for an individual student's IEP.

Figure 22.13 shows the Buddy Points management system. The system defaults to all check marks. If a student is absent, staff enters an "A" and if the student does not in fact earn a check, an "X" is entered.