

Golem: The Vehicular Robot Project

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ABSTRACT

One of the most pressing problems in robotics is the need to sense the outside environment. Rather than dealing with a self-contained software system, robotics systems almost invariably require reliable and accurate sensing mechanisms, which dictate behavior. Our research attempts to implement sonar-based sensing for a large-platform robotics project, and integrate the resulting data into a navigational program for said project. We began by selecting appropriate sonar subsystems on the basis of availability, ease of use, and accuracy. We then designed and constructed a power supply to drive the sonar transducers, and hardware to interface the sonars to the microcontroller responsible for navigation. Further, we built transducer mountings to ensure reliable and consistent sonar operation. After considerable testing and debugging of the sonar support hardware, our research moved to designing software for both low-level sensor monitoring and high-level navigational decisions. Finally, extensive testing was done to verify the performance of the sensing systems in real-world environments, and ensure that the navigational systems performed well in a range of situations.

INTRODUCTION

The purpose of the research was to implement a sonar-based navigation system for a vehicular robot. For a robot to achieve unattended operation, it is necessary to provide sensors suitable for performing collision avoidance. The robot must be able to detect and avoid potential obstacles. In directed systems, where the robot is attempting to achieve a specific goal, it must also be able to traverse an environment, circumnavigating obstructions, while continuing to work towards its intended destination.

One of the most useful and easily interpreted types of data for performing collision avoidance is proximity/ranging information. If the robot can tell how far away the obstacles are, it can do a very effective job of avoiding them. While it would be ideal to have precise three-dimensional representations of every object in the environment, this is neither easy to collect, nor to interpret.

With limited computational power on board an autonomous robot, we instead desire sensors that can quickly acquire data from the environment, applying the results to a reactive control algorithm.

Commercially available sonar systems can provide that data. Typical systems fire a short ultrasonic pulse (above the range of human hearing), while listening for the return echo. By precisely targeting its return time, a very good estimate of the distance to the reflecting object can be obtained.

Golem, the robotics platform on which we performed our research, consists of a large

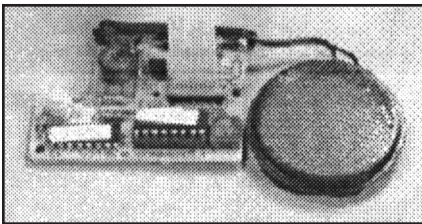
(approximately 3'x4') base, with a front swiveling caster, and two DC motors driving rear wheels through a chain drive. Onboard 12 volt deep cycle lead acid batteries provide power for the motors. Previous research had completed the task of constructing motor controllers to be used from a HandyBoard microcontroller.

IMPLEMENTATION

Hardware

After examining available sensor options, we selected the Polaroid 6500 series sonar ranging modules [fig 1]. The same modules are used in several models of auto-focus cameras, and provide good accuracy, as well as easy microprocessor interfacing.

Due to the fact that the sonar modules require approximately 2 amps of surge current during each 1 millisecond transmit cycle, a power supply was built around a standard adjustable voltage regulator [fig. 2]. This design can provide 1.5 amps at 6 volts continuously and easily handle spikes of greater amperage. Since our design is intended to support multiple sonars, only a single module should be fired at a time. Because firing several sonars simultaneously would result in confusing echoes, this proved not to be a serious problem.



- Range: 6" to 35 ft.
- Absolute Accuracy: +/-1%
- TTL compatible
- Supply: 4.5 to 6.8 V
- During Transmit: 2000mA
- After Transmit: 100mA

Figure 1: Polaroid Sonar Ranging Module

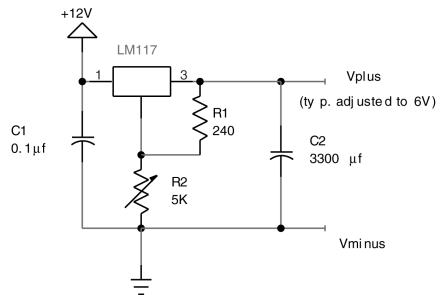


Figure 2: Sonar Power Supply Module

In order to correctly gauge distance, an accurate signal timer is needed. Since we already had a HandyBoard microcontroller in use for motor control, it was pressed into service for sonar timing. The HandyBoard controller is built around a Motorola 68HC11 running at 2 MHz, and provides several edge-triggered timers with half-microsecond resolution. Given the speed of sound, this results in sub-millimeter accuracy, which is more than adequate. Because the sonars would be fired separately, the echo result signals could be combined, and sent to a single HandyBoard timer input.

The stock HandyBoard design doesn't provide more than a few digital output lines. Since we wanted full control over the timing of the pulse transmission, it was necessary to add additional output lines. This was accomplished by tying a standard HC374 Flip-Flop to the HC11 data bus, utilizing a spare clock line to trigger it. Due to the memory architecture, this provided simple I/O control, allowing us to load a value in a single location to control the state of all the output lines.

Given 8 digital outputs, we decided to allocate 6 to triggering specific sonar units, and one to control the “blanking inhibit” feature of the sonars. This is a feature to control how long the sonar unit waits to begin listening for an echo. If the time specified is too short, it will frequently false trigger, due to the transducer unit “ringing” from the transmit cycle. If the time specified is too long, the sonar will be unable to detect objects extremely close to the transducer. After experimentation, this delay was set to 500 microseconds, approximately equal to the round trip echo time for 9 centimeters. The one remaining output was left unused, but could be utilized for the “multiple echo” detection feature of the Polaroid modules.

In interfacing the sonars to the controller, we discovered that they would not produce reasonable echo times unless the sonar and HandyBoard power supply grounds were tied together. This was likely due to a “floating ground” condition, where the controller was unable to determine when the echo line became asserted. Another problem uncovered during testing involved poorly fitting connectors, which could cause entirely random range results.

Once the interfacing issues were resolved, the last piece of work to be done on the hardware was to determine placement and mounting of the transducer units. During testing, we utilized duct tape to secure the transducers in appropriate locations. It was soon decided that this mounting method lacked the robustness desired in an autonomous system, so we switched to angle brackets, screwed to the top cover of the robot platform. The transducers were then secured with zip ties, a configuration which has proven to be mechanically solid, and easy to adjust.

Although initial work only used three of the sonars, we quickly added sonar units, bringing the total to four forward-facing, and two back-facing. Arranged on a rectangular platform, two of the forward modules were placed in the outside corners, facing out at a 45 degree angle from the front edge. The other two front modules were placed perpendicular to the front edge, distributed equidistant from each other and the outside modules. The backwards modules were placed similarly to the forward outside modules, to provide the best coverage for backing up and turning simultaneously.

Software

Building off existing sample code provided for the HandyBoard, we then wrote code to fire the sonars in a continuous loop, saving the echo time from each, and performing unit conversion to simplify the higher-level control functions. At “top speed,” the complete set of 6 sonars can be swept 20 times per second, allowing immediate feedback on changes in the environment. Although better accuracy could be obtained by compensating for air temperature and other factors, we used 345 meters/second as our estimate of the speed of sound at sea level and room temperature. With threading capabilities provided by the Interactive C runtime environment, it was a simple matter to run the monitoring procedure concurrently with the motion control algorithms. One slight limitation of the existing timing mechanism is that it relies on a 16-bit free-running counter with half-microsecond resolution. Because we wanted to reject “lost echoes,” we interpreted the elapsed time as a signed value, and moved on to a new sonar unit once it had gone negative. This allows a maximum range of about 2.8 meters, far under the potential range of 10 meters. Although it would be desirable to either count timer overflows, or use a lower resolution timer clock in order to extend the range, this was not a major limitation. The robot rarely needs to worry about obstacles greater than a couple meters away, particularly with indoor operation.

From that point on, it was a relatively simple matter to develop collision-avoidance soft-

ware. A simple reflexive algorithm was used, essentially “shying away” from any obstacles encountered. This is relatively trivial to implement, representing a system of “inhibitions”:

1. Set both motors full ahead.
2. If leftmost forward-facing sonar detects an obstacle, slow down right motor proportionally to its distance.
3. If rightmost forward-facing sonar detects an obstacle, slow down left motor proportionally to its distance.
4. If any forward-facing sonar detects an obstacle closer than a pre-set threshold, stop, and attempt to back away, then resume forward operation when free of obstructions.

With appropriate tuning, this algorithm allowed for fairly reliable autonomous roaming behavior. The main problem encountered was that extremely narrow obstacles (such as the dividers between hallway doors) were sometimes not detected by forward facing sensors. Although we were able to make adjustments to the sonar configuration to fix some of these instances, we decided to continue to utilize our previously constructed front bumper sensor as a backup to the sonar. Obstacles below the view of the sonar can still cause difficulties, as do tables, but we are confident these issues can be resolved.

Additionally, the rear-facing sonars are employed to watch for obstacles while in “back-up” mode. Having only two, in a crowded room it will sometimes back into a person’s leg if they are standing directly behind the platform. This behavior is only particularly undesirable if it happens to one of the designers, and we are careful to avoid this circumstance. Ideally, additional sonars would be added to improve front and back ranging capabilities, but this would require additional design work on the interface board.

RESULTS

The results of the research were very encouraging-

- After a long stint of debugging, the sonar hardware seems to be quite robust, and supports up to 6 sonars.
- Software support works very well for its intended use, with enough precision and speed to support the navigation program.
- The navigational program is very capable of avoiding obstacles, and can generally run with minimal supervision for long periods of time.
- Ongoing research has added a camera, utilizing it for motion-detection, proving the feasibility of other, supplementary sensing systems.

Ongoing and future work includes:

- More advanced navigational algorithms.
- Further integration of additional sensing systems, including vision, and other types of proximity detection.
- Tightly integrated control from higher-level processors.
- Utilization of additional sonars.

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A Study of a Housemound at the Site of RBS-2, Belize, Central America

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INTRODUCTION

During the summer of 1998, I conducted excavations in northwestern Belize. The purpose of my excavations was to show that a small mound located next to a medium sized plaza group functioned as a Maya housemound and was contemporaneous with the Tepeu 2/3 plaza group, dating to the Late Classic from about A.D. 700 to 900. Our excavations uncovered the mound to be residential with two possible construction phases dating to the early and latter parts of the Late Classic.

My research was carried out during the sixth field season of a twenty-year project known as the Programme for Belize Archaeological Project, hereafter referred to as PFB-AP. The PFB-AP is a collaborative effort incorporating professional archaeologists, graduate students, and undergraduate students from many universities in the attempt to recover and gain more insight into the ancient Mayan world. The project focuses on the daily lives of non-elite Maya and the social and political organization of a large region, called the Three Rivers Area. The area gets its name from the three rivers running through it. They are the Rio Hondo to the north, the Boothe's River to the south, and bisected by the Rio Bravo. Although my research is only a small part of the overall project, it makes relevant contributions to our long-term goals.

The PFB-AP is located in the northwestern region of Belize on the Programme for Belize Reserve, a 229,000 acre archaeological and wildlife conservation area (Kathryn Reese-Taylor personal communications 1998). La Milpa, the third largest Maya site in Belize, is also located on the PFB property.

Jon Hageman, a Ph.D. candidate at Southern Illinois University, is working on his dissertation project in this area. My excavations were part of his project that focuses on the identification of individual lineages and their territories on the ground through a program of survey and excavations (Jon Hageman personal communications 1998).

The structure that I excavated is located adjacent to a medium sized plaza group known as RBS-2 or "Liwy's Group". Liwy's Group lies on the periphery of the larger site of Dos Hombres. The plaza group consists of four structures with two mounds adjacent to it. I worked on the larger of the two mounds. There was a second smaller plaza also nearby.

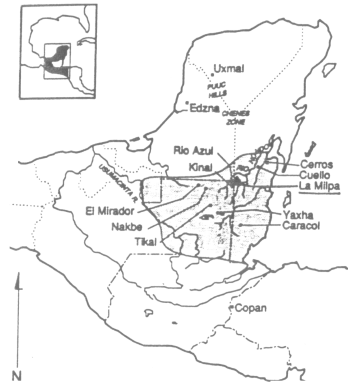


Figure 1: Map of Maya area. Site of La Milpa located in northwestern Belize (Adapted from Scarborough 1998:2).

METHODS

The recovery and research methods we used were based upon our one-month time frame, a crew of four to five workers, the equipment available, and most importantly our goals. Our crew consisted of myself; Jarius Beck, an undergraduate student at the University of Texas at Austin; site director Liwy Grazioso Sierra, of the Anthropology Museum in Mexico City, and a steady crew of Wisconsin and Texas field school students.

We began with finding the corners of the mound so that we could take measurements and map it. The mound measured about 2.5 meters by four meters and was oriented east/west. We had to extrapolate the west side because there were two huge trees on it that had caused major root disturbance. The mound was about 50 cm high along the north side and 100 cm high along the south side.

Our next step was to carefully set up two, one by three-meter units. The first unit was set up north/south perpendicularly to the south side, while the second unit was set up north/south perpendicularly to the north side. Later we opened up four more units of various measurements, ending up with units in the southwest and northeast corners, and also the center of the mound. In total, our excavation units transversed the entire north/south span of the mound.

We set up a 1/4 inch mesh screen to sift through the contents of the mound and began slowly taking the units down by cultural levels. We regularly assessed the unit profiles and composition to see if there was a change or consistency somewhere in the construction material, architecture, or fill.

RESULTS

On the surface of the mound we were able to see a few larger rocks that had probably made up a portion of the structure. We were careful at first to leave all of the rocks as we had found them so that we would not destroy any of the architecture. However, after studying the rocks we realized that many of them had fallen out of place and were acting as more of a hindrance than an aid in helping piece together the architecture of the mound. So, with the help of experienced archaeologists, we mapped and photographed the rocks, then removed them.

Just under the humus layer, along with some of the larger fallen rocks, we found irregularly shaped limestone rubble with a heavy, dark brown clay loam matrix throughout the units. In the first few lots there was a great amount of organic debris scattered throughout the soil, but it eventually vanished and limestone and other lithic debris became more common.

At 20 cm below the surface we encountered a scattering of irregularly shaped, melon-sized limestone rocks along with grapefruit sized cobbles and a fill matrix that was a medium brown with a sandy texture. Then golf ball sized limestone cobbles appeared at 33 cm below the surface along with a light brown, loose, sandy fill. This slowly turned into small pebbles at 37 cm below the surface with a fill matrix that was lighter in color and looser in texture. This was very interesting because the southwest plaza group was significantly different, being primarily constructed in large rubble, about 25 to 50 cm maximum in diameter.

The walls of the platform were made up of three to four courses of laid limestone measuring about 59 cm high along the north wall and 52 cm high along the south wall. The stones were irregularly shaped, except for the cut facing stones. On the north wall we noticed the biggest cut stones between 53 and 64 cm below the surface. These stones were all aligned with each other and stepped back slightly. They may have been used as a retaining wall. I did not notice this type of stepping on the south wall. The innermost course of stone on both

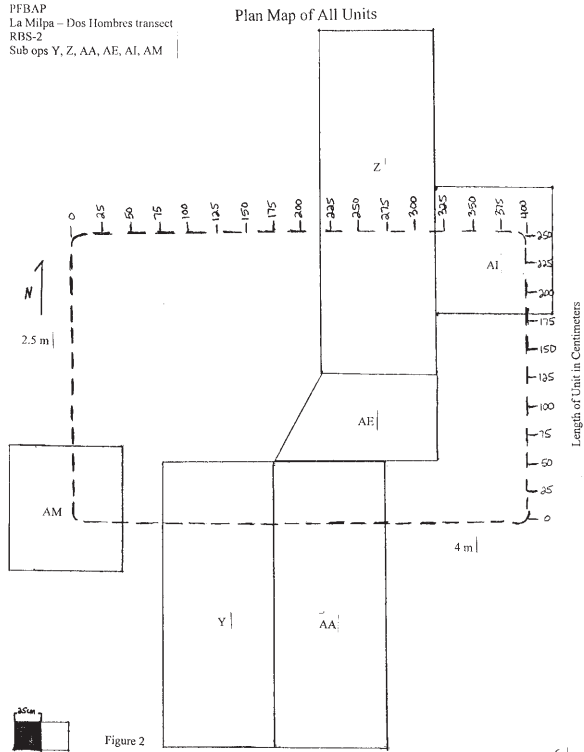


Figure 2

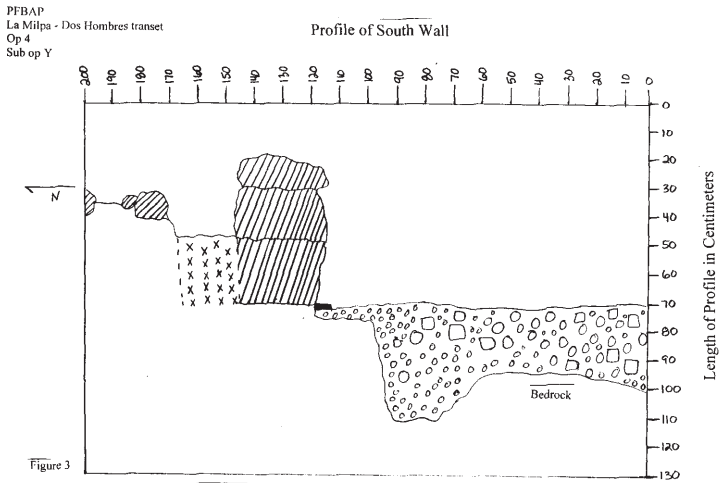
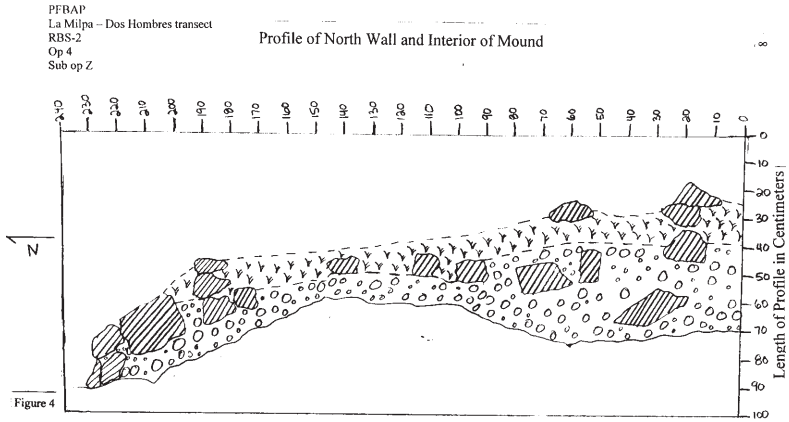


Figure 3



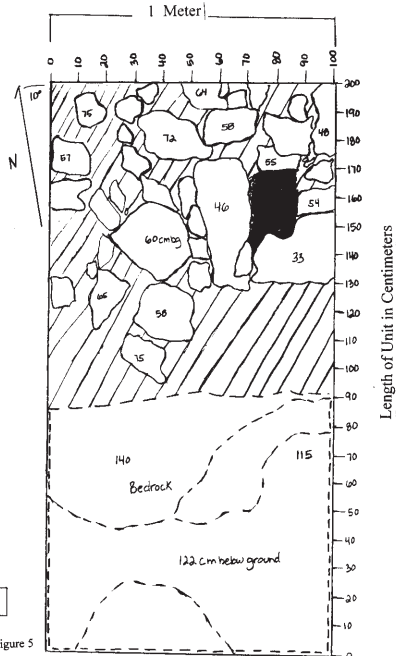
- Key
- Humus layer
 - Limestone blocks
 - Golf ball-sized cobbles
 - Pebbles



Figure 4

PFBAP
La Milpa - Dos Hombres transect
RBS-2
Op 4
Sub op Y
Lot 4 - 6

South Wall



- Key
- Limestone
 - Fill matrix
 - Bedrock
 - Posthole
- .mbg = cm below ground



Figure 5

walls was either crudely cut or not cut at all and were smaller, about the size of a melon.

The northeast corner of the walls were fit together nicely. Bedrock was shallow on this corner of the mound, measuring on average only 54 cm below the surface and was used as part of the foundation. Limestone cobbles were placed on top of the bedrock, forming a solid corner. The bedrock did not seem to be reshaped at all. This was very different from the southwest corner. Here bedrock was much deeper and did not seem to be used for the wall construction.

We found one posthole. It measured 16 cm by 24 cm, and was 26 cm in depth. It was cut into the stonework on the south wall. This posthole was located almost in the center of the south wall, where there is about a 50 cm break in the wall. We interpreted this opening as a possible entrance. We opened up a unit in the southwest corner in hopes of finding another posthole.

Unfortunately, we did not.

As we excavated the inside of the platform we found few artifacts: some small ceramic sherds, fragments of chert, one crude biface, and obsidian microblades. The concentration was dispersed throughout the mound, although ceramic debris was especially heavy outside of the structure. We found no faunal or plant debris.

In the center of the mound we came down on a plaster floor at approximately 35 cm below the surface. This indicates that either there were two construction episodes to the platform or we encountered the plaza surface. Although the plaster had deteriorated a bit, we could tell that it had been smooth and very hard. The color was grayish. The construction fill was a light brown color with a pebbly to sandy texture. Less cultural material was recovered in this fill.

Interestingly, the plaster surface in the center of the mound had been broken away at some point. Since we found the plaster floor in the corners of the interior units, we presumed that it had extended throughout the center of the mound. As we assessed the center of the mound, we noticed that there was a slight depression where the floor had been punched out. The disturbed area measured 110 cm north/south and 90 cm east/west.

When we continued to dig on the floor of this same area, the construction fill changed to an off-whitish, loose, sandy matrix, and dirt began to slip through the cracks of the rocks. At

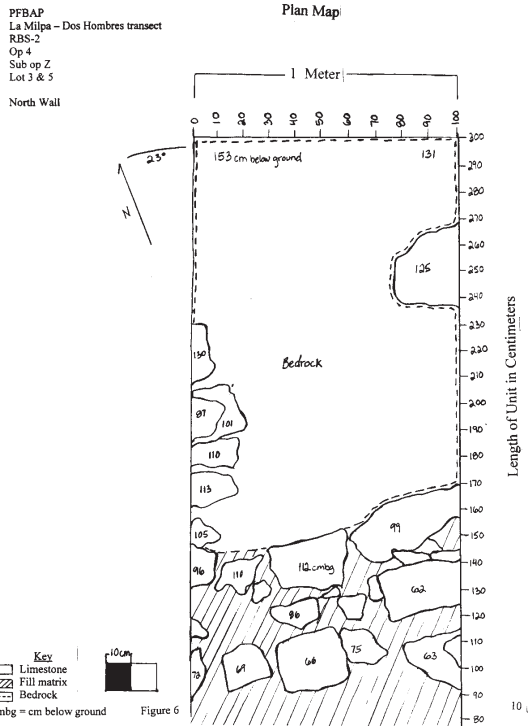


Figure 6

the bottom of this level, at 61 cm below the surface, the limestone cobbles had also gotten bigger, to approximately the size of a fist. We also noticed more cultural material.

The size of the disturbed area suggests a burial. Burials are commonly found in Maya housemounds beneath the floors. However, because we were at the end of our field season there was no time for proper recovery of a possible burial. Therefore, we terminated the excavations at 61 cm below the surface.

DISCUSSION

Our artifacts were few in numbers, but we were able to date the structure from the ceramics recovered. The ceramic analysis indicated that there were at least two construction episodes in the Late Classic, one dating from the early Late Classic, from about A.D. 700 to 800, and one to a latter phase in the Late Classic, from about A.D. 800 to 900. This interpretation is also supported by the ceramic data from the large plaza group.

An admixture of ceramic types from the Chicanel, 300 B.C. to A.D. 250; Tzakol, A.D. 250 to 600; and Tepeu 2/3, A.D. 700 to 900 (Smith 1955) spheres associated with the plaster floor and the disturbed area was found below the upper platform. This admixture was also recovered outside of the south wall at a depth of 45 to 64 cm below the surface.

The upper platform contains ceramics only dating to the Tepeu 2/3 period. Since both platforms contain Tepeu 2/3 ceramics, we know that the earliest possible construction of the structure was about A.D. 700, dating to the early Late Classic. While the second construction episode contains only Tepeu 2/3 ceramics, would date to a later phase in the Late Classic. This ceramic sequence shows that there were most likely two construction periods.

Bowl and jar sherds made up the majority of the forms found, but there was diversity in the type and variety of the ceramics. The jars probably had globular bodies with medium to thick sides and flat or ring bottoms. The bowls likely had flaring sides and a rounded lip. There were some basal flanges found in the Tepeu 2/3 period (Smith 1955).

Most of the ceramics were monochrome or dichrome slipped, but some were unslipped. Red, orange, and black were the most common slips. However, weathering may give inaccurate results of their true color.

Our lithics collected were mostly comprised of chert flakes and debitage. However, we did find one crude chert biface in the center of the mound, at 19 cm below the surface, just below the humus layer and above the light brown, fist size cobble fill. We also found seven fragments of prismatic obsidian blades in various locations. Four were found outside of the south wall, one outside of the north wall, and two in the center of the mound.

From ethnographic records and previous excavations in the Maya area, we know that the Maya built perishable structures atop small platforms. The walls of these perishable structures were constructed of upright poles daubed with plaster, or more likely mud. The roof was likely thatched (Abrams 1994).



Figure 7: contemporary Maya housemound (Whitlock 1976: 136)

This type of wattle-and-daub construction is very common throughout the Mayan world.

There are many reasons to believe that this mound was residential. First, in our excavations we found that the platform walls were three to four courses thick with cut facing stones, as well as thick retaining walls. Second, we found a posthole possibly indicating a doorway. Finally, we uncovered a plaster floor, something that would not be found in a storage building. The size and substantial construction of the platform indicate a significant investment of labor and resources. The Maya would not have invested this much time and means into a storage structure but would have in a household structure.

Wendy Ashmore and Richard R. Wilk (1988) define a household as “a social unit, specifically the group of people that shares in a maximum definable number of activities, including one or more of the following: production, consumption, pooling of resources, reproduction, coresidence, and shared ownership” (Ashmore and Wilk 1988: 6). According to Ashmore and Wilk, “households are fundamental elements of human society, and their main physical manifestations are the houses their members occupy” (Ashmore and Wilk 1988: 1).

As indicated by Diamanti (1985) and others, food preparation and consumption, craft production, and other activities were not being done inside of the houses. The artifacts we found were for utilitarian use and are found mostly outside of houses. As previously stated, the ceramic sherds were formerly jars, bowls, and other utilitarian vessels. Nevertheless, some of the small fragments were found inside the structure mixed in with the construction fill.

Very few artifacts or soil stains were found inside of the house structure also suggesting that the structure was most likely used mainly as a sleeping area, with all other activities taking place outside. The small size of the mound suggests that the house had only one room. According to Sheehy (1985) and Ashmore and Wilk (1988), single room structures were occupied by an average of five people, comprising a nuclear family.

Ashmore (1981a) defines this type of residential structure as a minimal residential unit. This structure type is the basic building block of the lowland Maya settlement. It refers to a single, small, structurally isolated building that serves as the residence of a single nuclear or biological family (Willey 1981).

When comparing the ceramic analysis and architecture of the house and nearby plaza group, it seems that they are contemporaneous with each other. Jon Hageman’s research of the plaza group uncovered the same type of ceramic distribution, revealing two construction episodes dating to the early and latter parts of the Late Classic. He also proposed that the plaza group is the residence of a lineage head because it is among the largest architecture in the area and contains a shrine on the east side (Jon Hageman personal communications 1998).

In conclusion, the data recovered from the excavations of this structure has led to the following interpretations: First, the platform served as a foundation for a perishable, single-room house likely occupied by a family of five. Second, the platform has two construction phases, one dating to the early part of the Late Classic period and one dating to a latter phase in the Late Classic. Lastly, the construction phases of this house are contemporaneous with those of the large plaza group.

Therefore, because of the housemound’s proximity to and contemporaneity with the plaza group, I propose that it was occupied by a nuclear family closely related to the lineage heads during both construction periods.

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