Towards intelligent autonomous digger *)

Tadeusz Szuba (head of group)
Agata Straś, Robert Straś,
Andrzej Król, Adam Niezgoda,
Krzysztof Jędrzejek,
& (undergraduate students).

University of Mining and Metallurgy, Institute of Computer Science, 30-059 Cracow, Poland, al. Mickiewicza 30 paw. C-2.

Summary:

Our research group is engaged in the researches on the problem of robot-digger. Our view point is located on the area of applied artificial intelligence, for which the robot digger is the excellent object to combine different areas of artificial intelligence into one quasi-intelligent & autonomous system. The considerations refer to the following problems: necessary 3-D vision system, representation of the surrounding world in robot consciousness & transformations of the world during action planning, action planning proces for outrigger & body movements, organisation of the computational process in the on-board computer of robot-digger.

key-words: artificial intelligence, intelligent & autonomous system, robot-digger, action planning, 3-D vision, contact human-foreman # robot-digger.

1. Introduction

Since 1986 our group has been working on the problem of robot-digger for earthworks, waste dump works, loading works etc. We suppose, that robot-digger will play the same key-part in the development of computer controlled machines, as Numerically Controlled machine tool. From the theoretical point of view N.C. machine tool and robot-digger/loader represents the same class of cutting machines:

- N.C. machine tool works on the internal scene (located inside the machine). Scene (work-table) is the element of the machine tool and is fully controlled (e.g. turned) by machine tool.
- robot-digger/loader works on the external scene (located outside the machine). Robot-digger is the element of the scene and controlls the scene only in the restricted manner.

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From the geometrical point of view, digging process and cutting process may be treated as the same process of shape transformations with the different degree of uncertainty. The slope falling down after the spoon-up is the element of such scene uncertainty. Robot-digger/loader is much more complicated than machine tool is, on almost all levels of applied artificial intelligence:

- 3-D vision system is absolutely necessary for robot-digger (in modern machine tools the forefather of 3-D vision systems appears in the form of measuring tools);
- action planning for N.C. machine tool is restricted to a gripper and tool movements. For the robot-digger action planning is widened onto digger movements planning in the area of building ground;
- man-machine contact for modern machine tools is based on computer graphics as the element of CAD/CAM system which is integrated with N.C. machine tool. For robot-digger the animated cartoon is necessary to inform what the autonomous machine plans to do;
- necessary computer architecture to control the working machine grows from a single CAD/CAM oriented unit for machine tool into on-board, network-based computer with high computational power for robot-digger.

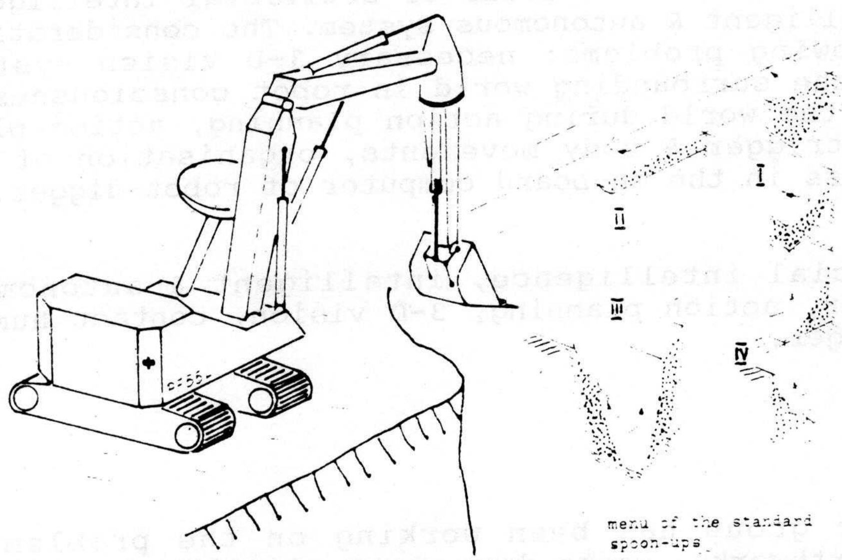
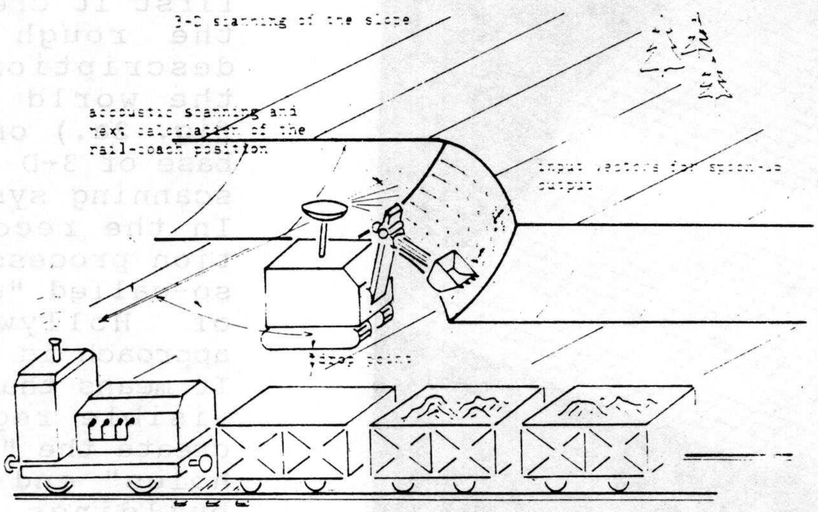


Fig. 1a. Extreme representants of the digger-robot family.

Because the final construction of the robot-digger is a very expensive enterprise, and hazardous from economical point of view, our group concentrates on the hardware & software problems. We simulate computational processes which will take place in and around a robot-digger. As the veryficator we use 3-D high-resolution graphics and micro-model on micro-scene. This model is based on stepping motors with specially designed controller card plugged into PC AT. This PC simulates the node of on-board computer network, which is responsible for Direct Numerical Control Functions.

In the past five years we analyzed the activity of possible variants of robot-digger. It becomes evident that the family of robot-diggers has two extreme representatives as in figs 1a,b.

Than we analyzed and subsequently designed the necessary form of the contact digger-robot # human-foreman. In such the digger-robot all elements of idea are close connected to each other and the modification of one element influences very strongly the other component. So we have defined the frames of 3-D vision system on the base of 3-D laser scanning system which will be supported by microphones (accoustic scanning).



On this base the model of the surrounding world transformations were established and action planning strategies were designed. The mentionned above problems generate the computational processes in the on-board computer of digger-robot. We had investigated the problem how to make parallel such computations and how to distribute

Fig. 1b. Extreme representants of the digger-robot family.

these computations onto processors which create network based on-board computer.
The results we have achieved during our investigations and simulations (on the subproblems mentionned above) are described below. The accuracy of the description is restricted by the imposed size of this paper.

2. Scene description and activity of the robot-digger.

To simplify the idea of robot-digger/loader we had preassumed that such an intelligent & autonomous machine works on the closed range/building_ground. Such a machine operates individually or as an element of a group of machines, but the machines don't cooperate. Only loader and lorry cooperate, which transport out the output. The autonomous machines are under the control of human-foreman who generates tasks to be performed, helps in difficult situations and controls the situation on building ground.
This assumption has the following very lucrative consequences:

1° we may base vision system on 3-D scanning laser. If the staff is trained and equipped with goggles, the low-energy laser is admissible. It implies on the base of avalanche effect the simplification of object recognition procedures. As the forefather of our 3-D vision system we assume system [V4] from Oulu Finland;

2° if the surrounding of robot-digger is closed to the set of well known objects, we may use accoustic system to perform:

a) rough observation of the surrounding on the base of broadband microphones;

b) digger-robot may recognize objects on the base of their accoustic characteristics;

c) directional microphone may be used to locate the direction and distance to the objects which had suddenly appeared

So assume, that digger-robot is weaked-up to active life on the given building ground. At first it creates the rough 3-D description of the world (see fig. 2a.) on the base of 3-D laser scanning system. In the recognition process the so-called "walls of Hollywood" approach is used. It means that not visible regions create the "black holes" end e.g. buildings are treated as the set of visible walls with black hole in the background. During action planning process such a terra incognita is treated as: "flat area" or "inaccessible region" depending on the additional elements of a situation in a strategy. During further activity these "black holes" (or terra incognita) are updated, completed and e.g. walls of house are closed into full shape.

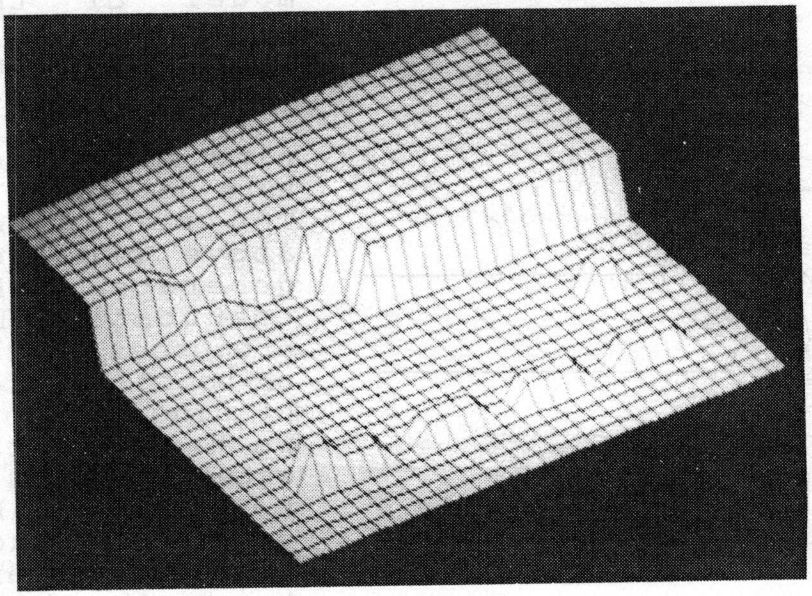


Fig. 2a. Example of rough description of the scene.

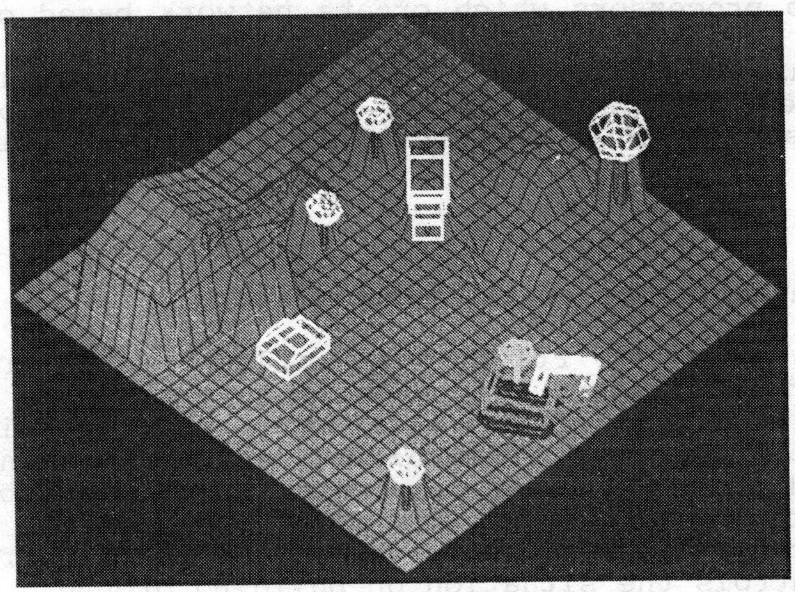


Fig. 2b. Example of scene after recognition process.

In the next step of digger's consciousness activity this rough world model is postprocessed in the following way:

I) the objects on the scene creates until this moment (e.g. moving lorry) only the disturbances of the surface (moving disturbance). Now on the base of accoustic recognition or shape recognition, 3-D descriptions of recognized objects are overlapped on these disturbances. It may be e.g. shape of the lorry taken from computer memory. The modelled example of such recognition may be seen in fig 2b. In our idea of robot-digger there is identity between: computational world model, world model on which the future activity of robot-digger is presented to the human-foreman and the world created by 3-D scanning laser (it creates cartographical description);

II) scene description is transformed from 3-D to 2-D model on the base of-so called balance (stability) calculations. It very simplifies the action planning process. The idea of this transformation will be described in paragraph 3, which discusses action planning problem.

Now digger-robot has to receive the order/task what to do from the human-foreman. The most complicated form of the task is:

"perform excavation <on the base of contour description> in the region of scene which is distant from the present position of robot-digger".

This is the most complicated variant, because on the action planning level the robot-digger has:
- to find the route from given position to the region of future earthworks;
- to solve the problem how to digg;
- to find the return route e.g. to digger' s yard. This seemingly simple problem appears very complicated if we take into account that robot-digger may cutt-of its return path while working in deep excavation.

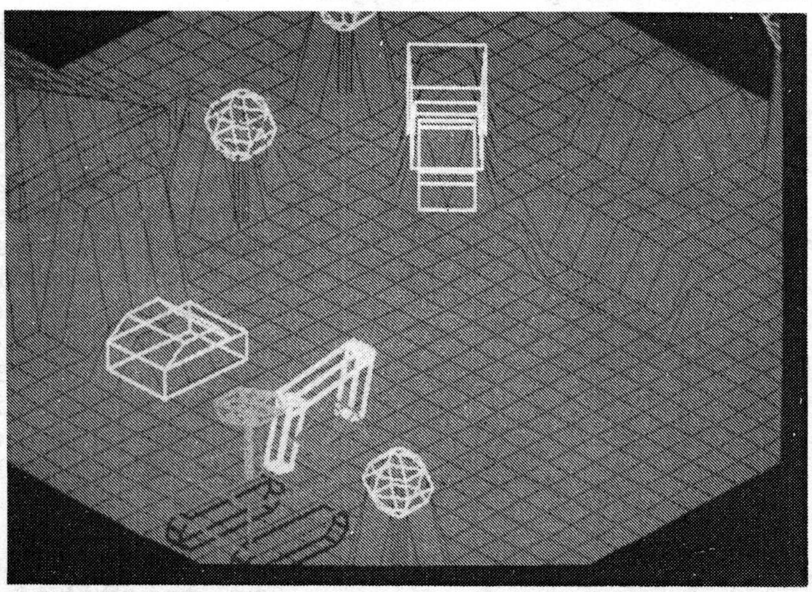


Fig. 3. Slide from animated cartoon - what digger-robot plans to do.

Suppose that action planning had been done (successfully or not). Here appears the problem how to organize effectively the contact man-machine in severe climate of the building ground. Due to our considerations, the best way is to equip human-foreman with lap-top computer with the following elements of internal equipment:

- high contrast SuperVGA graphic card to display animated film about the intended activity of robot-digger;
- voice processing card + microphone to reduce the use of keyboard in range conditions. Due to our considerations such a card has to process ≈ 200 words and may be trated also as the access-key (digger-robot will understand only one man);
- radio-based LAN card (Local Area Network) to connect human's lap-top computer with on-board computer of robot-digger. Such LAN cards are now available e.g. ARLAN from Telesystems LSW

Don Mills Ontario Canada;
- we see that high-power Intel 80486 based lap-top is adequate for such a purpose.

On this base robot-digger may present its future intentions in form of animated cartoon. On such a film dialog windows may be overlapped, so it makes the contact easy and safe. A slide from such a film about digger's plan is presented in fig. 3. It appears, that relatively simple animated cartoon describe situation and the plans of robot-digger excessively. This approach simplifies also the so-called HELP problem. Every situation on building ground which causes the blocade of digger-robot activity may be displayed on human's lap-top computer for analysis. At last the correct picture created by vision systems (for example fig. 2a, b) may be displayed.
On this base human-foreman may drive directly the robot-digger, if the situation is not within possibilities of the action planning module.

3. Action planning, parallel computational processes in on-board computer.

Action planning for robot-digger has two levels:
- route planning from e.g. digger's yard to region of excavation;
- planning of the movement of scoop + outrigger.

Route planning may be done relatively easily if we are able to transform 3-D scene into 2-D representation. Consider figs 4 a,b,c which describe our idea of such transformations. 3-D scene from fig. 4a may be reconsidered by robot digger from the point of view of its balance, such as described in fig. 4c. It may be seen that

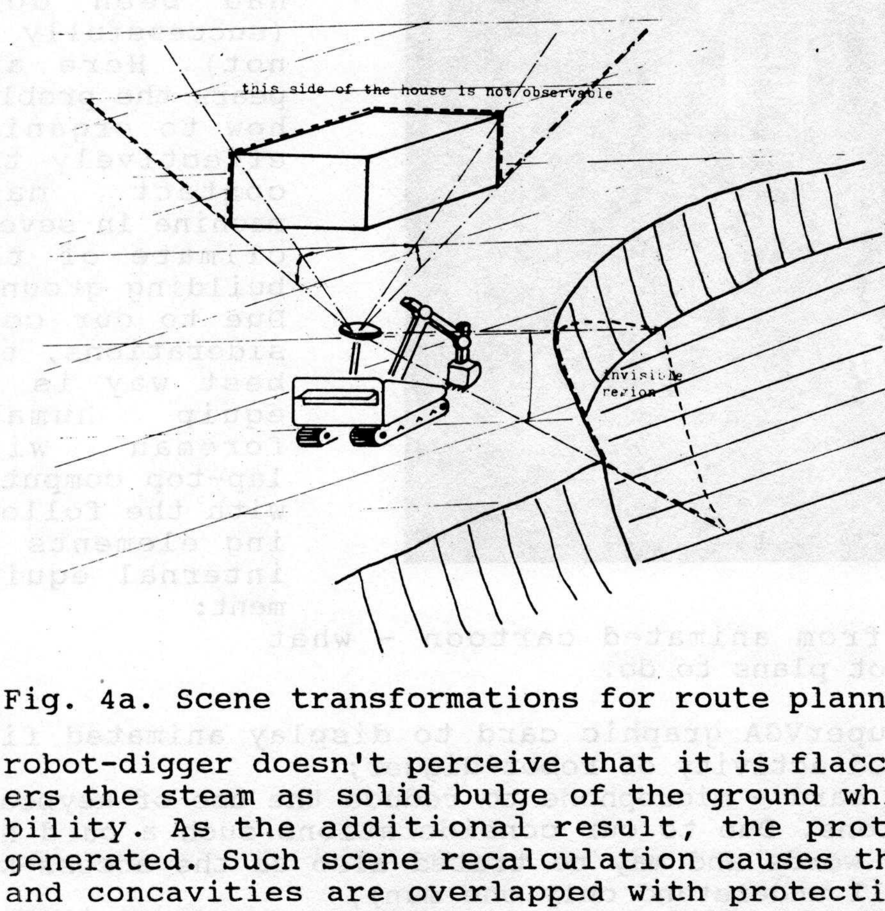


Fig. 4a. Scene transformations for route planning.

robot-digger doesn't perceive that it is flaccid tree, but considers the steam as solid bulge of the ground which may cause instability. As the additional result, the protection envelope is generated. Such scene recalculation causes that essential bulges and concavities are overlapped with protection envelopes and we get 2-D scene. Now we may use one of well-known paths planning algorithmes e.g. [R6], [R7]. The second level of action planning is planning of the movements of scoop + outrigger. Our research group has designed and tested the resticted action planning system SASP integrated with package for contact of human-operator # robot-digger. It is obvious, that the computational power installed in such a intelligent & autonomous robot-digger will be great.

So to do this job well from the computer science point of view, we defined the model of on-board computer and we dissipated and parallelized the calculations in SASP package. The general model of the on-board computer is presented in fig. 5. More details about this on-board computer and software parallelization and dissipation may be found in [K8].

In SASP package action planning is done in 2-D. This assumption is strengthened by the assumptions that body of the digger is fixed (works only scoop + outrigger) and drop point over the lorry is constant and well-known. So

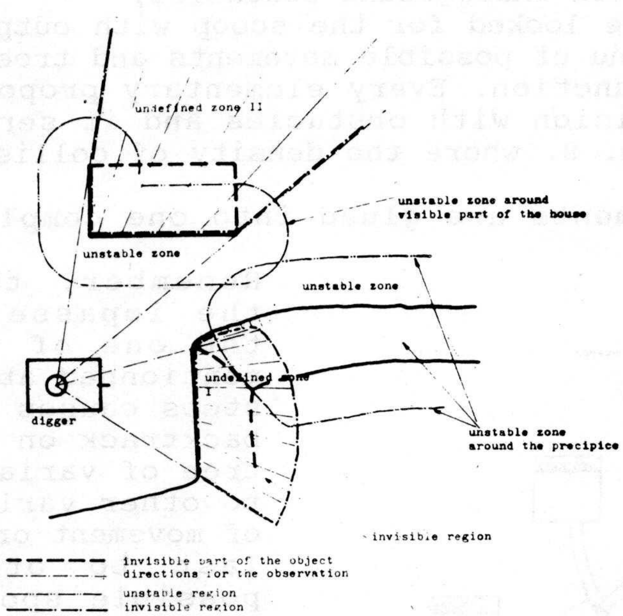


Fig. 4b. Scene transformations for route planning.

this package is not appropriate for robot-digger/loader which after the spoon-up commes up to the lorry to drop the output into platform. In this package at first the surrounding of the digger-robot is defined geometrically as it is depicted in fig. 6. It is equivalent of the activity of vision system and the contact with

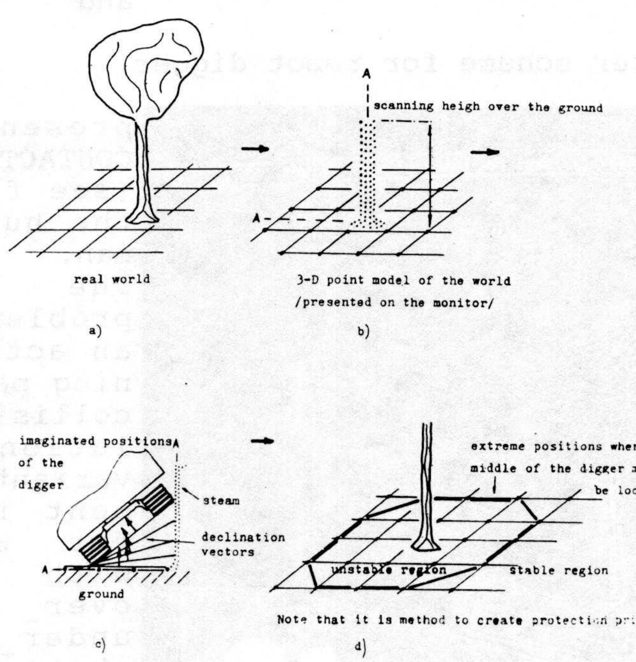


Fig. 4c. Scene transformations for route planning.

human-foreman, which defines e.g. underground obstacles.
Next the desired excavation (defined by the human-foreman in form

of contour on the screen) is quantized into set of all possible future spoon-ups. Elements of such set create the starting tree of variants. Now those elements are taken and tested one by one:

- at first the necessary movements of scoop are defined (see fig. 7) and tested on collision with underground obstacles;
- next the return-movements are looked for the scoop with output. It is done on the base of menu of possible movements and tree of variants with evaluation function. Every elementary proposed movement is tested on collision with obstacles and if servos allow this movement. See fig. 8. where the density of collision calculations are depicted;
- at last the lists of movements are glued into one complete working cycle.

Remember, that the impasse of the one of the mentionned above steps causes the backtrack on the tree of variants to other variant of movement or at last to other possible spoon-up.

This strategy is described in more details in [K6].

The results of such an action planning were composed into the animated cartoon and presented on CONTACTER monitor (see fig. 5) to the human-foreman.

The greatest problem in such an action planning package are collision calculations. Every variant of movement is tested for collision with ground, over_ and under_ground obstacles. So such a calculations are done

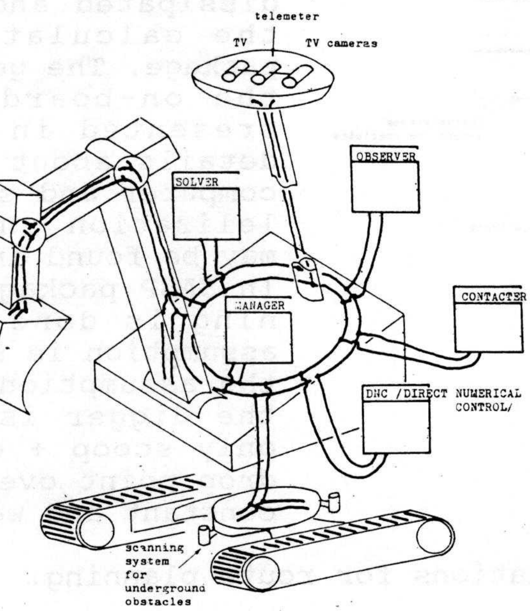


Fig. 5. On-board computer scheme for robot digger.

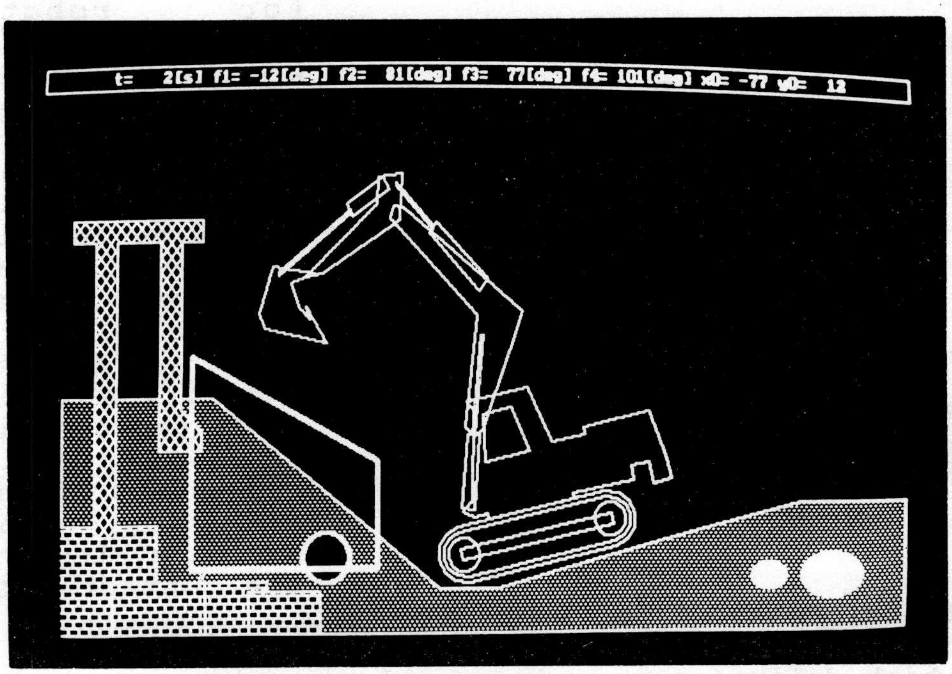


Fig. 6. Scene to plan 2-D movements of the outrigger.

many thousands times in every cycle of action planning. For 2-D planning of movements, Intel 80486 processor is minimum, but for 3-D robot-digger/loader special collision processor is necessary.

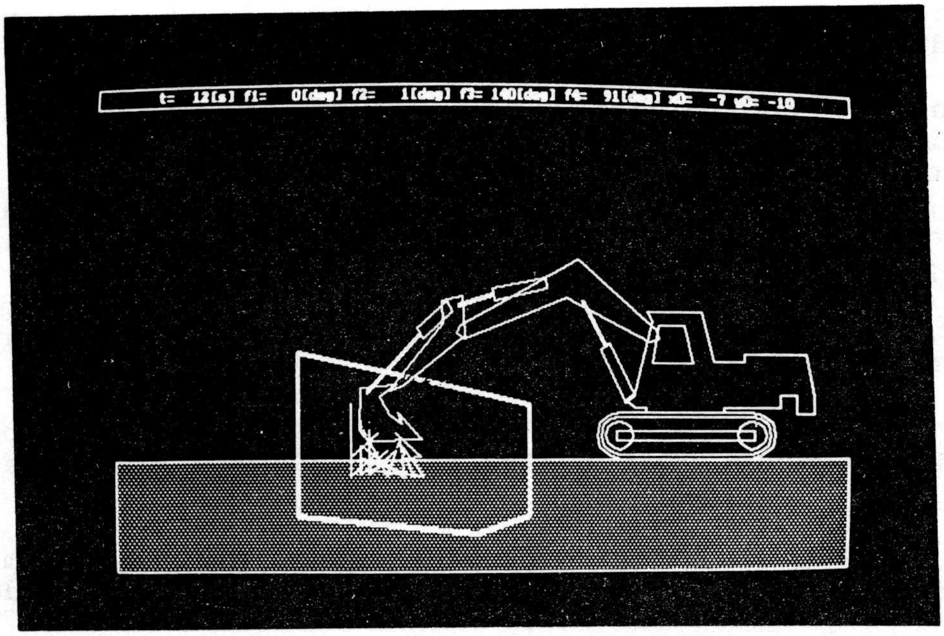


Fig. 7. Movements of the scoop.

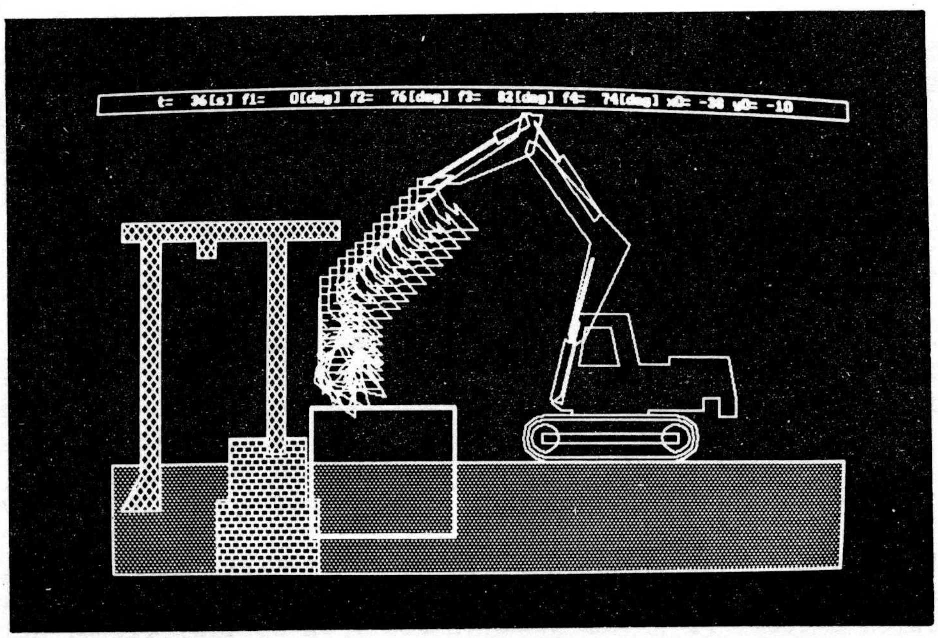


Fig. 8. Movements of the outrigger.

4. Future plans.

The financial resources of our group are restricted. So present directions of our activity are:

- to integrate route planning with planning of the digging process. In the past the simplified versions of software were designed mainly to reach the experience and to evaluate the

problems. Now the base graphics is 1280 x 1024 with full 3-D approach;
- our digger-robot "will be forced" to come-up to lorry to drop the output into the platform;
- the idea of on-board computer will be developed as the base to distribute and parallelize calculation process in our digger-robot;
- because we can not build a real digger-robot now, the plan of actions automatically synthesized will be next:
  a) presented for acceptance to human-operator;
  b) if accepted, the sequence of action will be time-scalled and
  c) observed on micro-model in micro-scene for technological correctness;
- the so-called collision-processor is so important, that we work also on the transputer system which will solve this problem better als normal processor does.

In our simulations we take into account also the effect of slope failure after the spoon-up. This software will be ready in June-July.

Our greatest problem now is the lack of laser based vision system. We have no money to build it now and the so-called OBSERVER node in on-board computer is simulated only.

So hereby we are looking for sponsors for our project or other research group which in frames of cooperation will fulfill our needs.

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