An Optic Technique for

Sorting Potatoes from

Stones and soil clods

by

Arthur Mason

Project
336-490D

MacDonald College

McGill University

Ste-Anne-de-Bellevue

OBJECTIVE

The purpose of this report is to investigate the reflectance characteristics of light on potatoes,stones and soil clods,and with this knowledge attempt to construct a model separation unit for these materials.

This report is submitted to complete the requirements for the Senior Projects course 336-490 N

Acknowledgment

I wish to express my gratitude to Dr. Raghavan, Dr. Norris, Reid Natress and a special thanks to my Father, all whom aided me for the duration of this course.

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INTRODUCTION

Harvesting Methods and Equipment

Mechanical harvesting of potatoes as opposed to hand harvesting is often used in Canada and The United States. Although these two methods achieve the same end, mechanical harvesters,working on large areas,are more efficient,require less time and are generally the accepted method.

Mechanical harvesters perform the following operations:

(1) Digging.

(2) Separation of loose soil,small clods and stones.

(3) Removal of vines and weeds.

(4) At least partial separation of the tubers from similarly sized stones and clods.

In hand harvesting, the potatoe digger performs only the first two of the above listed operations. The materials which are not separated by the digger are deposited in rows, then are hand separated. The potatoes are then delivered to controlled storage .

On a mechanical harvester complete separation is not generally obtained initially, therefore the machine requires from two to seven individuals to complete the process. Once this is achieved the potatoes are ready to be conveyed to a truck or bin by belt conveyance.

This automatic method is called direct mechanical harvesting.

A second automatic method of harvesting potatoes may also be employed. It is somewhat simular to direct mechanical harvesting with the difference being that the process is completed in two separate stages, with two different machines. Firstly, a digger windrower, generally two rows, but frequently modified so as to permit up to six rows, digs up the potatoe and windrows them. Here they may sit up to three hours before a harvestor, simular to that used in direct harvesting, but with a modified blade, picks them up, separates them, and conveys them to a truck or bin. This method is known as indirect mechanical harvesting and is advantageous over direct when conditions are wet or weedy, but since the material is handled twice, the chances of tuber damage is increased.

Digging and Soil Separation

Digging and loose soil separation are the primary operations undergone in full mechanical harvesting. Different blade configurations, depending upon the soil type and condition, are employed to cut into the soil and loosen the tubers. Since blade depth controls the quantity of soil and potatoes which initially enters the harvester, the blade must be operated deep enough to recover nearly all of the potatoes without including excessive soil. For a blade depth of ten centimeters a two row harvester must be able to handle 8 to 10 tons of soil per minute if it travels at a rate of approximately 3.2 kilometers per hour.[2] Table I may help to illustrate the ratio of soil, stones and potatoes a harvester may have to handle for a given soil type and condition.[1]

Located immediately after the blade is a rod chain type of conveyor whose primary purpose is to allow loose soil and any other loose material whose diameter is less than the spacing of the rods to drop out and resume its place on the ground. The structure of the conveyor is such as to allow some initial separation to occur. It's efficiency is increased by self-agitation.

Agitation is achieved by offsetting every second or third link in the chain and by passing the chain

Soil Type & condition	Variety	Row Width (inches)	Soil		Clods		Stones		Plant Material		Potatoes	
			tons/acre	%	tons/acre	%	tons/acre	%	tons/acre	%	tons/acre	%
Sandy Loam (dry)	Majestic	28.0	458.5	95.7	Included with	Soil	7.2	1.5	1.1	0.2	12.4	2.6
Medium Loam Stony-Moist	Majestic	27.5	291.8	80.3	52.1	14.3	2.3	0.6	n.a.	n.a.	17.3	4.8
Medium Loam Very Stony -Moist	Majestic	27.5	244.0	72.2	1.0	0.3	77.6	23.0	n.a.	n.a.	15.5	4.6
Sandy Loam Very Dry	Majestic	28.0	355.6	83.9	55.9	13.2	----	----	1.9	0.4	10.4	2.5
Clay-Dry	Majestic	28.0	125.1	70.6	40.6	22.9	----	---	1.0	0.6	10.4	5.9
Clay Loam with Flints Moist	King Edward	28.5	160.0	76.8	23.9	11.5	18.4	8.8	1.1	0.5	4.8	2.3
		Mean	272.5	78.6	34.7	10.0	26.4	7.6	1.3	0.4	11.8	3.4

Table I. British Soils

over idlers of various shapes. Although this increases soil separation, the possibly of tuber damage also increases.

Vine Removal

Vine removal is achieved by a second rod type conveyor system established soon after soil separation has terminated. All the material which has been subjected to this soil separation process is then deposited upon another rod conveyor whose pitch is approximately 100 to 125 mm. This is just large enough to allow the potatoes and debris of similar size to drop down on to a cross conveyor leaving the vines and other trash above.

Tubers which may still be attached to vines which do not drop between the rods are detached by stripper rollers located at the end of the rod conveyor. A similar deviner may also be set up on the cross conveyor to eliminate vines still attached to tubers which have dropped through the bar conveyor .

Separation of Potatoes from Stones & Clods

Separation of the tubers is the final unit operation of the four previously mentioned, initiated by the harvester. There are many different methods, and proposed methods by which to accomplish this task, and such being the topic of this paper, no real depth of elucidation shall be conducted in this section. Details of these methods shall be introduced in the following sections.

ANALYSIS OF THE DESIGN OF POTATOE-STONE SEPARATION METHODS

As illustrated in Table 1, there is a huge amount of material to be handled by the potatoe harvestor. Out of the total input, potatoes comprise only 3.4 percent. Stones contribute 7.6 percent, and soil an overwhelming 78.6 percent.[1] It is apparent that the extraneous material occupies a volume several times that of the usefull crop.

In order to automatically separate these materials, a characteristic must be present which may be perceived by the separating mechanism, and which differs in the materials to be separated. When two of these materials are stones and potatoes, detectable characteristic differences which may be practically employed are difficult to isolate.

A third factor of equal importance is the fact that a tuber is reasonably susceptible to damage such as bruises and cuts which may easily occur during separation. The combination of these three points with respect to separation of potatoes from stones and clods makes the solution evasive and more research regarding this process is inevitable.

During analysis of this situation the first question which is bound to occur, is if this direct separation can be either eliminated or reduced. To totally eliminate the separation process the form of the potatoe and/or its configuration within the soil would have to be altered. This would imply modification of the potato plant as we now know it. A project of this nature is considered to be long term and although it was proposed as early as 1950[5], little has been accomplished pertaining to that field. Reduction of the separation process has also been proposed. This could be accomplished by limiting the number of stones in the field itself either through manual picking, a labor intensive operation, or by employing mechanical stone pickers. However, in addition to complicating the process and increasing the likelihood of problems by adding another machine, the idea of removing the stones from the soil profileis questionable as it may be related to accelerated erosion and related soil problems.

Since it appears that the separation process cannot be presently reduced or eliminated, the direct approach must be pursued, that is, direct separation. In order to approach this problem a more in depth investigation must be done with regards to illustrating what is actually being dug out of the ground by the harvester.

According to more recent work, the quantity of material which is lifted out of the ground by the harvester varies from 400 to 650 tons per acre. Included in this quantity are from 60,000 to well over 100,000 tubers, 25,000 to 55,000 stems still attached to the tuber, and up to over 100,000 stones of similar size to that of the potato.[5] The estimated number of soil clods is unknown, due to limited literature upon the subject. However, consideration must be given to a soil which is excessively stony and contains numerous soil clods as to its suitabiliy for tuber production. In short, these figures may be used with non-excessive error.

The main stages of potato harvesting, with the exception of the separation unit or units have already been dealt with. Therefore their introduction is unnecessary. Instead, the flow pattern initiated in the introduction will be resumed starting at potato separation from stone and soil clods.

When designing such a separation mechanism it is often profitable to examine other ventures into that field and to establish problem areas with such a device. Once these problem spots are established and understood it is possible to incorporate that understanding to the ideal model. The problems concerning separation are as follows.

(1) There is a large rate of objects to be handled and separated per unit time.

(2) The soil will vary in amount, moisture content and aggregate size.

(3) Varying amounts of soil and moisture will be on potatoes and stones.

(4) The separation device must have the ability to function in the presence of a small amount of organic matter.

(5) Potential damage to the crop.

(6) Property similarities of stones and potatoes.

(7) Variations about crop areas and motion of device due to field operations.

REQUIREMENTS FOR SEPARATION

To effectively design a mechanism to separate two or more materials from one another it is necessary to outline what is actually expected from such a unit. The following list has been composed with this purpose in mind, leading to an improved understanding of how the mechanism may be developed.

Pre- separation

(a) Separation material must be conveyed in some manner to the separator.

(b) Since only the separation of stones and soil clods from potatoes is to occur, all other materials must be previously removed or the device must be able to handle them.

Property Difference

(a) Since separation will be based on a property difference, this characteristic must be consistant under all conditions if separation is to be complete.

Sensing the Property Difference

(a) The sensor incorporated must be as consistant as the property. It should be able to consistantly distinguish between properties.

(b) Singularization to some extent must occur in order for the property to be sensed.

Force Application

(a) If separation is to take place, the result will be producing two sets of material moving relative to one another.

(b) Conversely, if one class of material is moved relative to another a separation force must be applied.

(c) There must be a direct coordination between the sensing unit and the separation of the two classes of materials.

(d) To prevent interference adequate singularization must be available for the two classes of materials.

Post Separation

(a) After separation the materials must be available for collection and transport from the separation mechanism.

Economics

(a) In addition to physical requirements,budgeting and cost considerations must also be included in such a list. The economic foundation behind the system must make it practical to produce and operate such a system.

LITERATURE REVIEW

Shotbolt Harvestor

The Shotbolt Harvester was first produced in 1952-53 in England and was one of the earlier commercial harvesters equipped with a potato,stone and soil clod separation unit. The device was very simple in principle The harvester dug up the tubers and then transported them across an agitator bar conveyor allowing the smaller debris to fall through. The remaining material would then be dumped into a vat containing a mud slurry which was fixed to the harvester. The potatoes floated atop the mixture,whereas the stones and clods sank to the bottom where they were frequently scraped away. The floating potatoes in turn increased in number which forced them over to a partially submerged belt conveyor where they were then withdrawn from the tank. This device was very simple,effective,required minimum power and provided for singularization and differentiation.

The property incorporated with this device was specific gravity,which is consistently different for potatoes,stones and clods.

From the graph of specific gravity vs material it can be seen that the specific gravity for all potatoes lie between 1.05 and 1.10 whereas for stones and

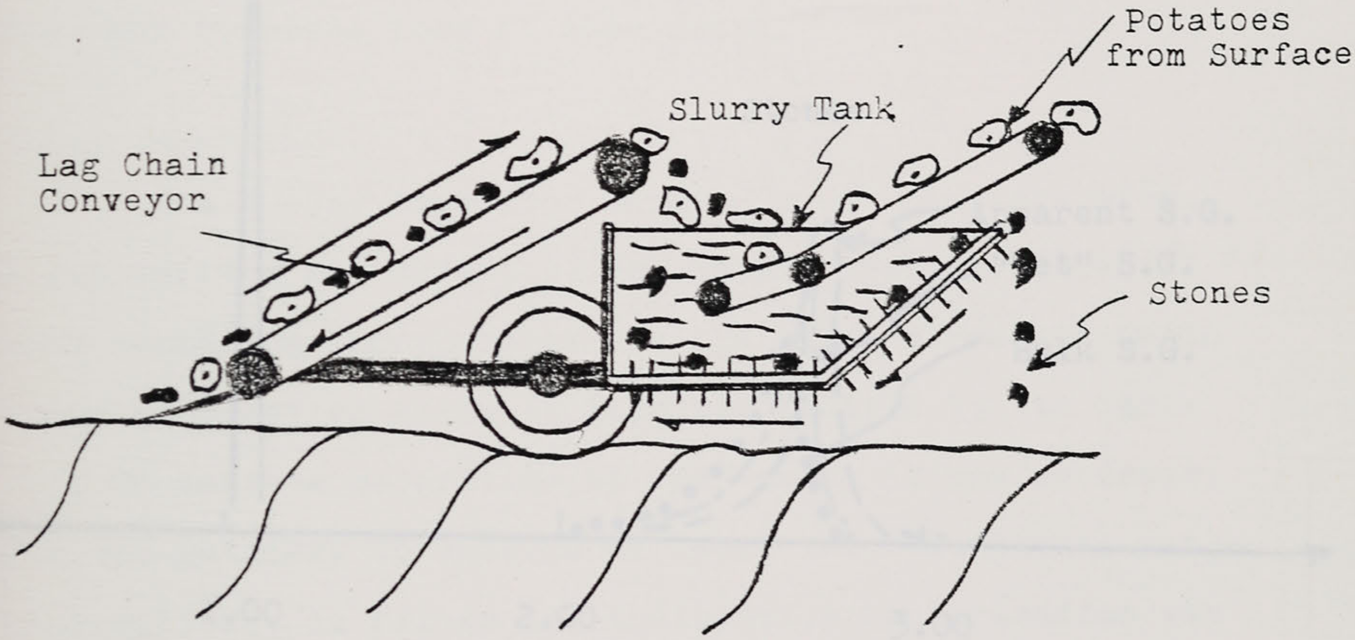


Figure A. Flotation Type Harvester

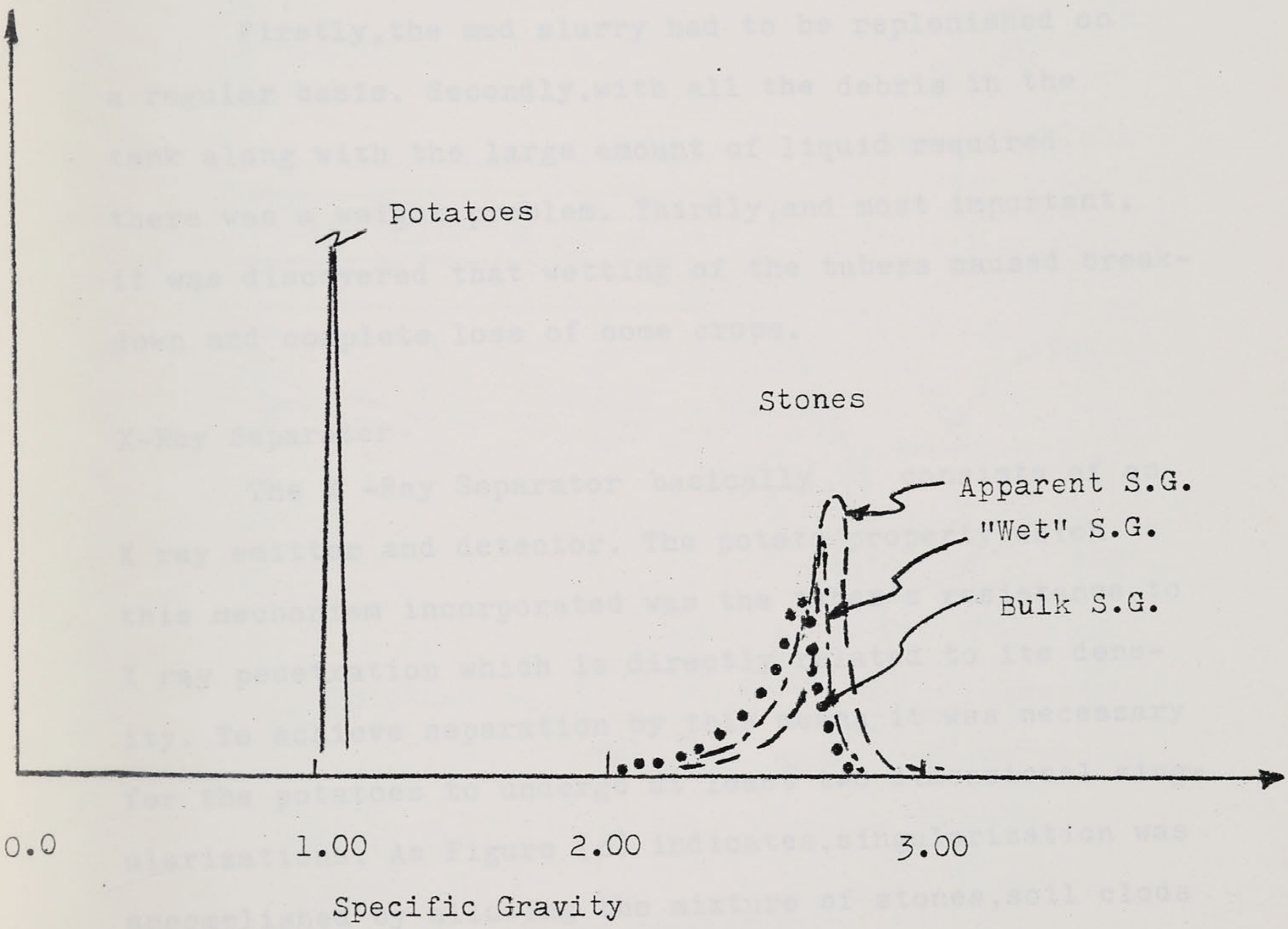


Figure B. Specific Gravity Distribution

soil clods it is never below 1.40 .[5]

This device also allowed for handling a large number of items per unit time with continuous sensing and gravity force application. There were, however, several problems.

Firstly, the mud slurry had to be replenished on a regular basis. Secondly, with all the debris in the tank along with the large amount of liquid required there was a weight problem. Thirdly, and most important, it was discovered that wetting of the tubers caused breakdown and complete loss of some crops.

X-Ray Separater

The X -Ray Separator basically consists of an X ray emitter and detector. The potato property which this mechanism incorporated was the tuber's resistance to X ray penetration which is directly related to its density. To achieve separation by this means it was necessary for the potatoes to undergo at least two dimensional singularizations. As Figure (c) indicates, singularization was accomplished by allowing the mixture of stones, soil clods and potatoes to fall off the end of a conveyor forming a vertical sheet directly in front of the emitter. Once a potato was detected, separation occured through the use of deflector arms.

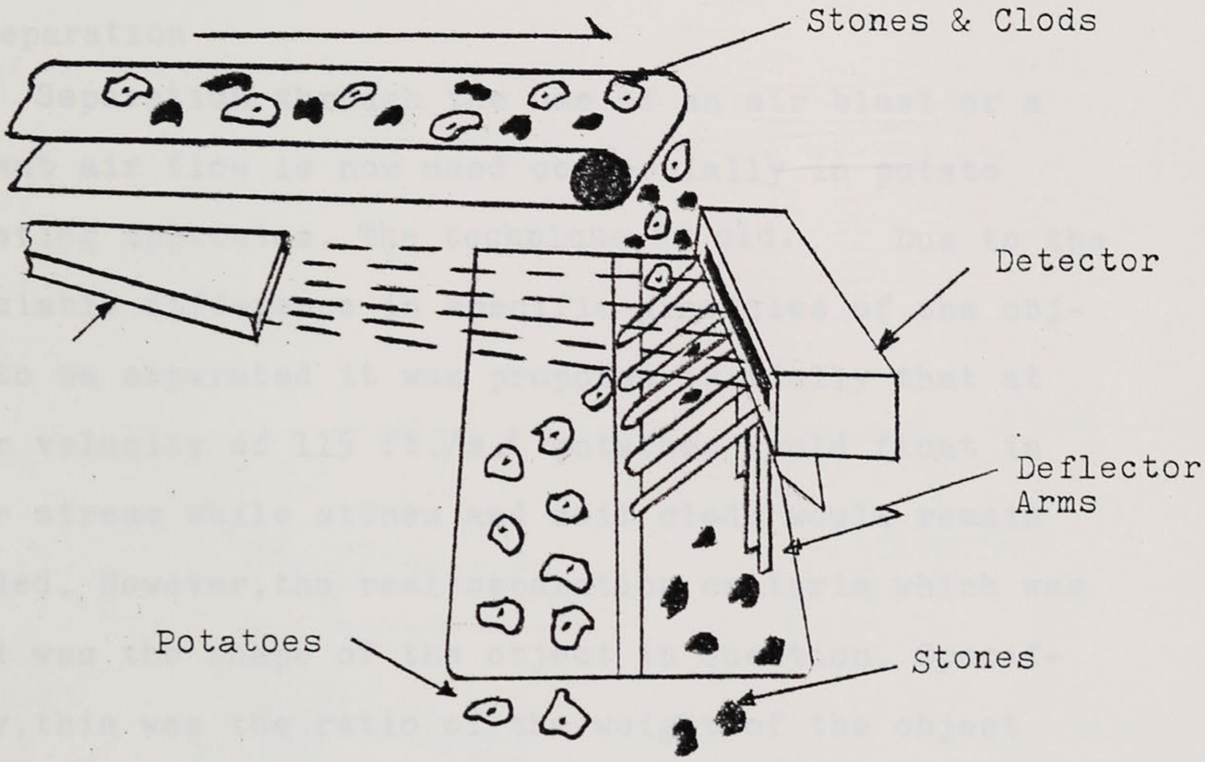


Figure C. X-Ray Separater

One problem with this type of machine lies in the singularization technique. Synchronization of the potato with a particular deflector arm was inconsistant due to lateral movement of the mechanism. Another problem arose due to the impact of the potatoes on the arms and with the belt conveyor after they had dropped.

Air Separation

Separation through the use of an air blast or a constant air flow is now used commercially in potato harvesting apparatus. The technique is old. Due to the appreciable difference in specific gravities of the objects to be separated it was proposed initially that at an air velocity of 115 ft./s.[2] potatoes would float in an air stream while stones and soil clods would remain grounded. However, the real separation criteria which was tested was the shape of the object in question. Specifically, this was the ratio of the weight of the object to its frontal area. This allows the flat, thin stones to float as easily in a fluid stream as potatoes. It was also found that due to the edge roughness of some soil aggregates, they too might float as this tended to increase their drag coefficient.

Another problem encountered was interference of air streams, or singularlization. This allowed a floating

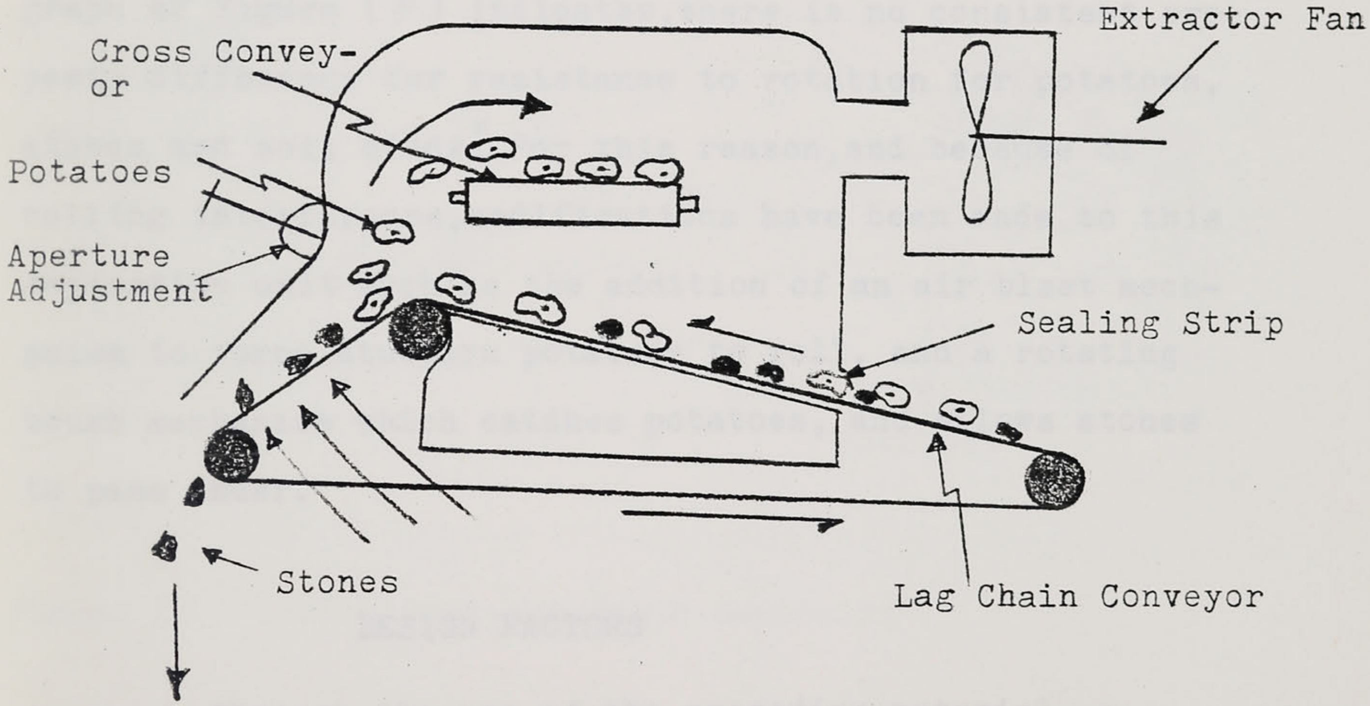


Figure D. Air Separation Unit

or suspended object to momentarily cut off the air way of another suspended object causing sensing and force application problems.

Belt Separation

The belt separator is a transversely mounted belt which takes advantage of the ability of the potato to roll,or its resistance to rolling to effect separation. As illustrated in Figure (E),a mixture of rocks,potatoes and soil clods is cross conveyed to a tilted belt conveyor where the separation takes place. Stones and soil clods were thought least able to roll,consequently they remain on the belt while the potatoes roll off. However,as the graph of Figure (F) indicates,there is no consistent property difference for resistance to rotation for potatoes, stones and soil clods.[5] For this reason,and because of rolling interference,modifications have been made to this separation unit such as the addition of an air blast mechanism to force stubborn potatoes to roll, and a rotating brush mechanism which catches potatoes, and allows stones to pass under.

DESIGN FACTORS

Through the use of the preceding material, a finalized list may be composed, whose contents are simply

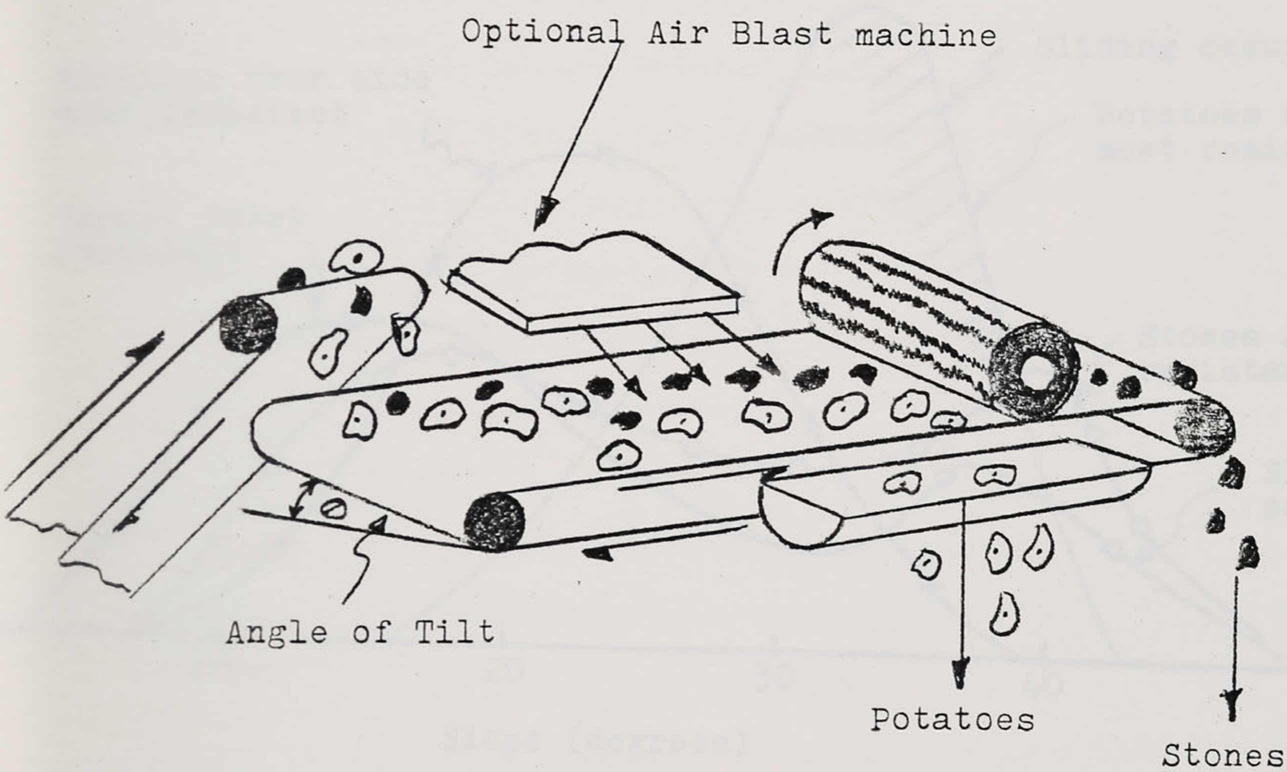


Figure E. Tilted Belt and Brush Separator

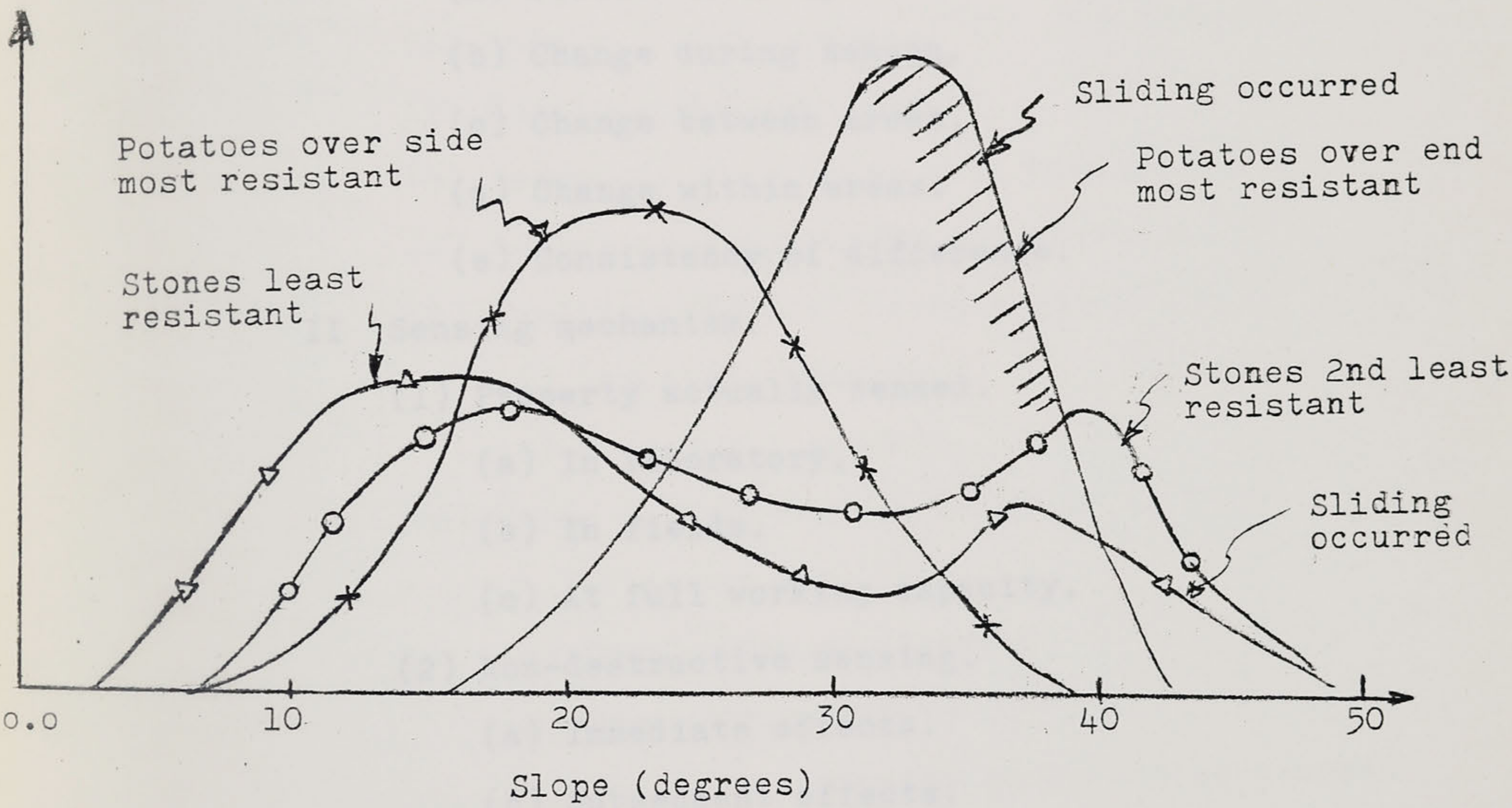


Figure F. Distribution of Resistance to Rotation of Potatoes and Stones a summary, identifying the factors involved in the design of a successful separation unit.

I Separation criteria.

(1) Property to be used.

(a) Single.

(b) Composite.

(2) Degree of difference.

(a) Percent overlap.

(b) Change during season.

(c) Change between areas.

(d) Change within areas.

(e) Consistency of difference.

II Sensing mechanism.

(1) Property actually sensed.

(a) In laboratory.

(b) In fields.

(c) At full working capacity.

(2) Non-destructive sensing.

(a) Immediate effects.

(b) Subsequent effects.

(3) Degree of singularization required.

(a) Mass.

(b) One dimensional (sheet).

(c) Two dimensional (line).

(d) Three dimensional (individual).

(e) Positioning - spacing of object.

(f) Orientation - alignment of object.

(4) Degree of singularization provided.

(5) Sensing in relation to flow of materials.

(a) Continuous or discrete.

(b) Remote or contact.

(c) Change in velocity or direction caused.

(d) Maximum rate possible per channel.

III Application of separation force.

(1) Integral with sensor.

(2) Coordination with sensor.

(3) Degree of singularization required.

(4) Degree of singularization provided.

(5) Quality effect of force application.

(a) Immediate effects.

(b) Subsequent effects.

(6) Force application in relation to flow of materials.

(a) Continuous or discrete.

(b) Direction relative to flow.

(c) Change of velocity or direction caused.

(d) Gravity effects.

(e) Maximum rate possible per channel.

IV Economic considerations.

(1) Weight and size of unit.

(a) Flotation.

(b) Traction.

(c) Maneuverability.

(2) Quality losses at field operating rates.

(a) Immediate.

(b) Subsequent.

(3) Cost for capacity.

(a) Initial.

(b) Operating.

To produce a capable mechanical potato harvester all of the above mentioned factors must be taken equally into account during the process of design.

If one was to be neglected or showed up to be weak in actual production or practice, the remaining factors would equally suffer, resulting in a possible failure of the mechanism.

SPECTRAL REFLECTANCE OF LIGHT AND INFA-RED RADIATION BY POTATOES, STONES AND SOIL CLODS

Reflectance Characteristics

In the last 25 years spectral reflectance tests have been performed on rocks, soil clods and potatoes. These tests provided evidence that reflectance properties of a potato were dissimilar to that of a stone or soil clod over a given range of wave lengths. As illustrated in Figure (4), page 19d, the percentage of reflectance tends to be higher for a potato between the 0.5 to 1.3 micron band and lower outside of it than stones or soil clods.[3] This appears to be a constant differential property, consequently it shows possibilities of playing a vital role in the separation process.

The Test

The reflectance test was performed by Story (1970) and utilized 10 potato soils from Colorado, three basic color type of potatoes and 69 stone samples from alluvial deposits of San Luis Valley. Their reflectance properties were tested on a Perkin-Elmer Model 450 double-beam ratio recording spectrophotometer equipped with an integrating sphere reflectance attachment which was modified to extend to the 2.5 micron wave length by the installation of lead sulphur cells within barium sulfate coated spheres.

Sample Preparation

Potato samples required very little preparation for the test and may be as catagorized. Stored, freshly dug potatoes, and varying potatoe color. Their skin condition was also indicated. Dehydrated and decaying potatoes were included in the tests.

Stone samples consisted of smooth as well as porous rocks and included rock of volcanic origin. Colors varied through light, dark and reddish.

Varying soil types were used in the test ranging from black clay loam to light colored loamy sand. The variable parameter tested in the soil samples, was moisture content. All soil samples were oven dried at 100 degrees C. until no moisture remained. Then varying amounts of water were added to each soil sample so as to test them at 10%,20% and 30% soil moisture on a wet basis.

Results of the Test

The results of the tests are shown in Figures (1),(2), (3) and (4), of pages 19, a,b,c,d. From these graphs it is clear that the potatoes display a higher reflectance than either stone or the soil clods between the 0.5 to 1.3 range with a relatively low reflectance outside of this band. Freshly dug potatoes appear to possess the highest reflectance within this range whereas dry or dehydrated potatoes display high reflectances outside of this range.

Implications

From the tests reported by Story (1970) it would appear that there is a method for the mechanical non-destructive separation of potatoes by use of their reflectance characteristics. The absolute differences in this property for stones,potatoes and soil clods, however,is not sufficient for complete separation. The ratio of reflectances within the 0.5 to 1.3 micron band to that outside of it ,however was found to be sufficient for complete separation.

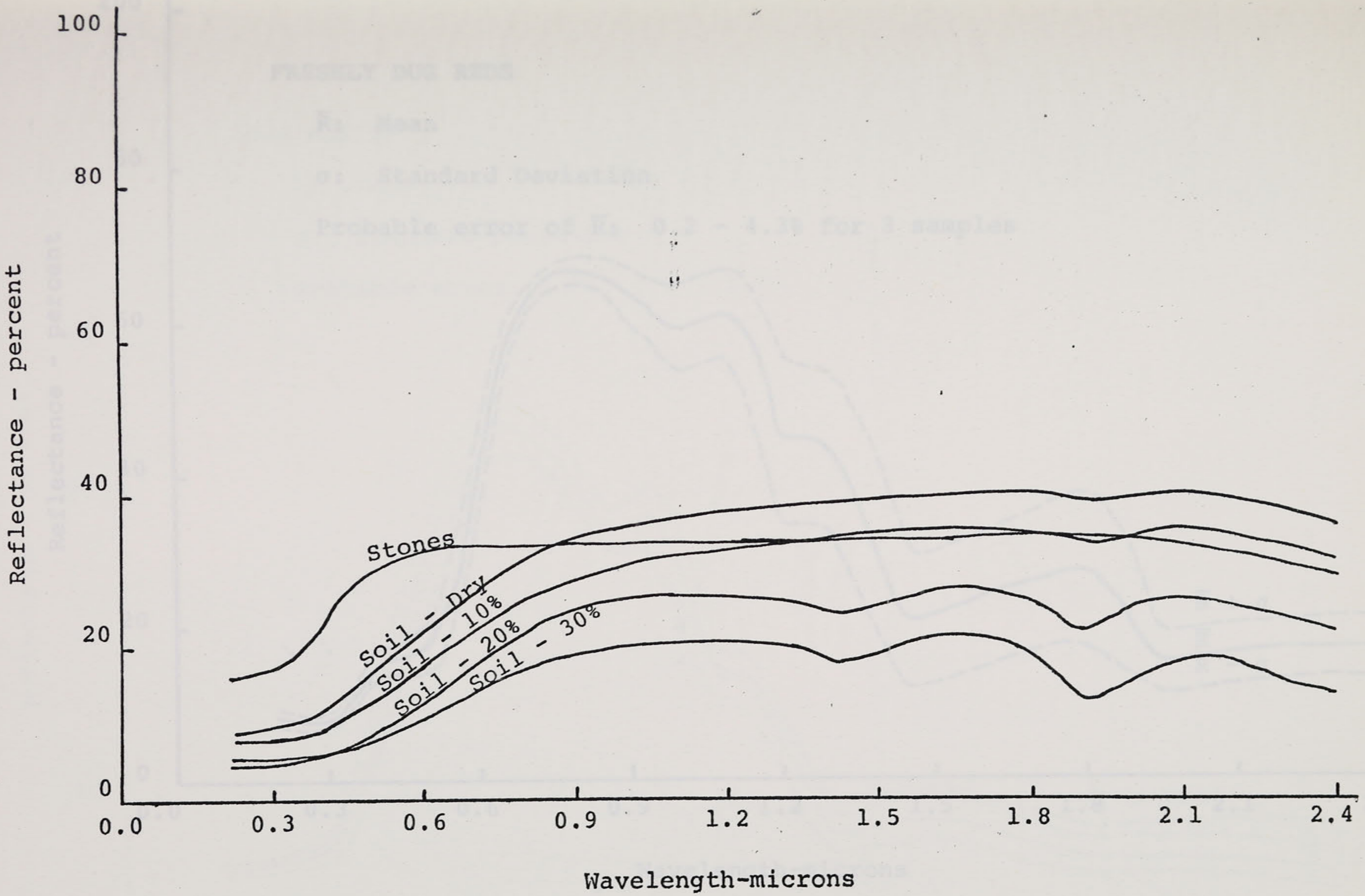


FIGURE 1. Mean Spectral Reflectance of Rocks and Soils

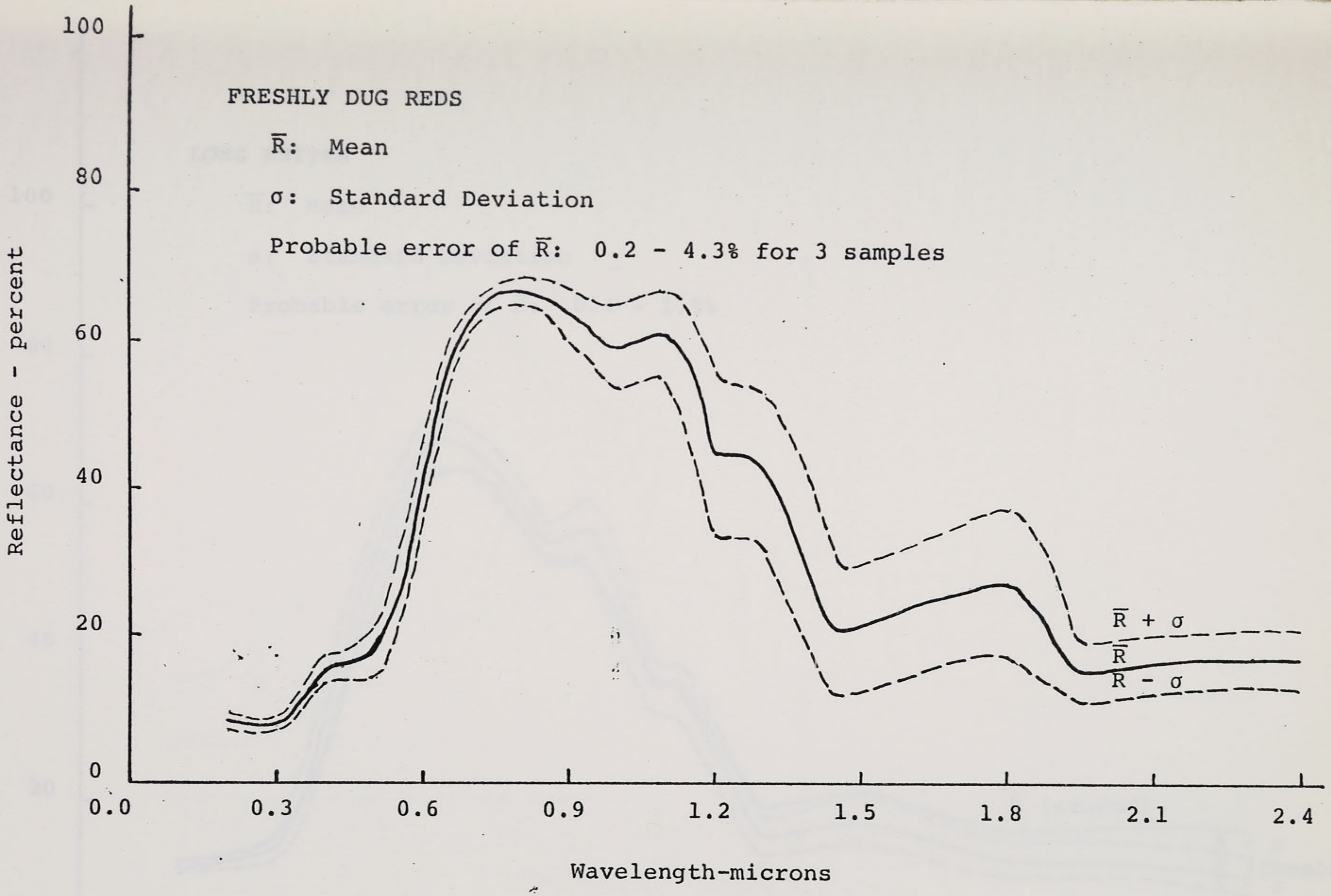


FIGURE 2. Spectral Reflectance of Potatoes

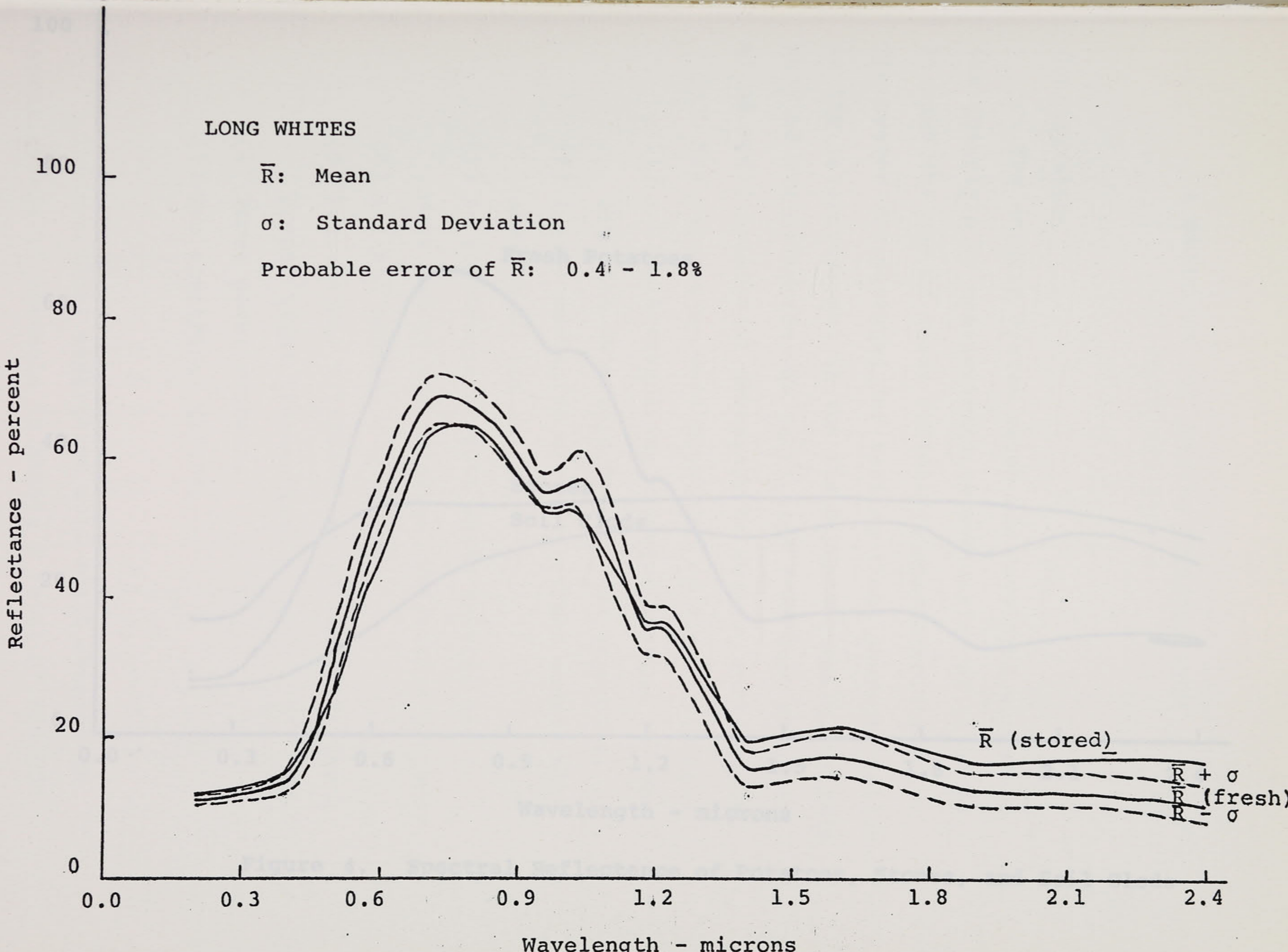


Figure 3. Spectral Reflectance of Potatoes

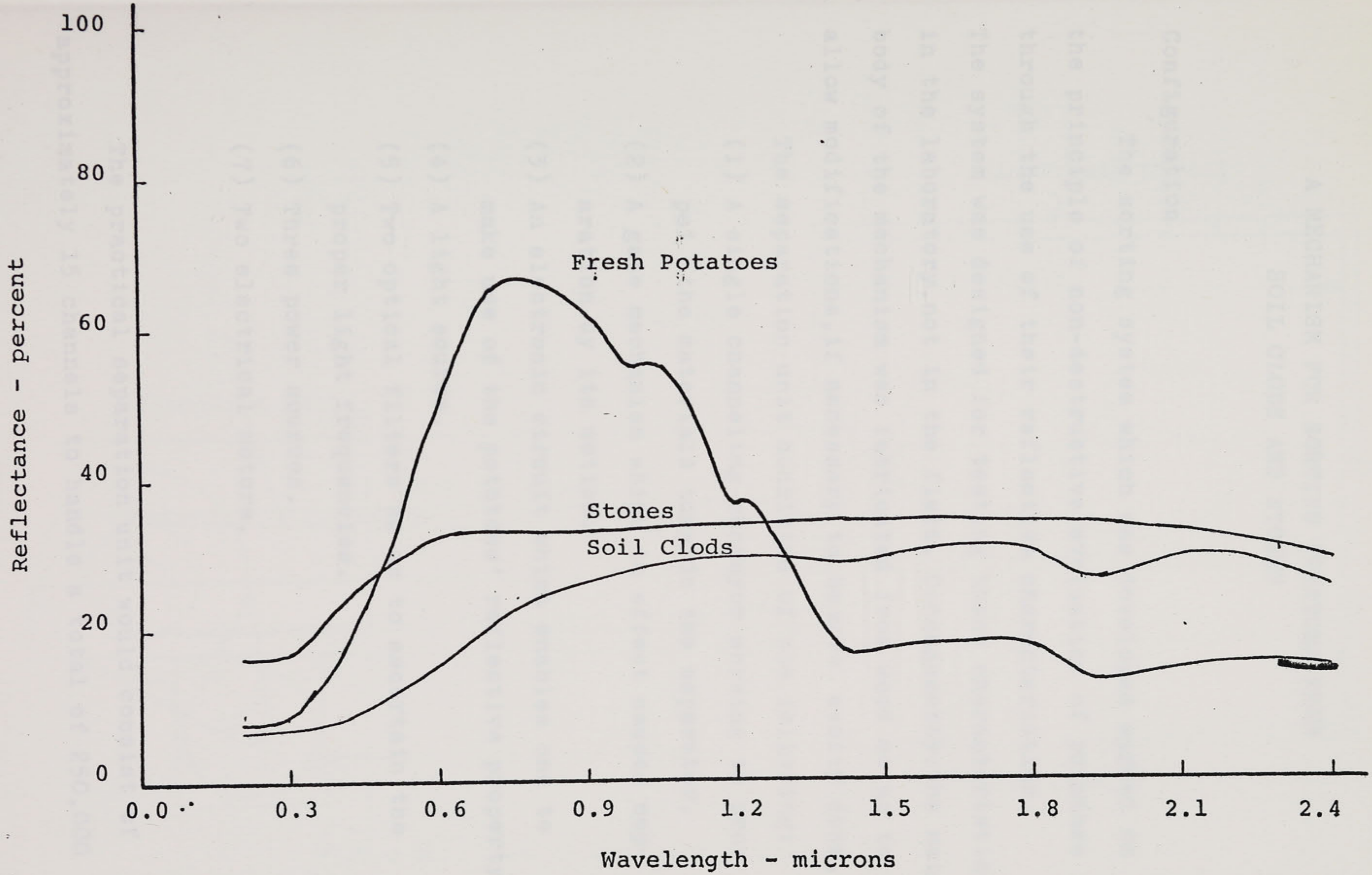


Figure 4. Spectral Reflectance of Potatoes, Stones, and Soil Clods

A MECHANISM FOR SORTING POTATOES FROM SOIL CLODS AND STONES

Configuration

The sorting system which was developed worked on the principle of non-destructive evaluation of potatoes through the use of their reflective characteristics. The system was designed for testing these characteristics in the laboratory, not in the field. Consequently, the main body of the mechanism was fabricated from wood so as to allow modifications, if necessary to be more easily done.

The separation unit consisted of the following:

(1) A single channeling conveyor serving to propel the materials towards the separator.

(2) A gate mechanism which in effect causes separation by its motion.

(3) An electronic circuit which enables one to make use of the potatoes' reflective property.

(4) A light source.

(5) Two optical filters so as to ascertain the proper light frequencies.

(6) Three power sources.

(7) Two electrical motors.

The practical separation unit would consist of approximately 15 channels to handle a total of 250,000

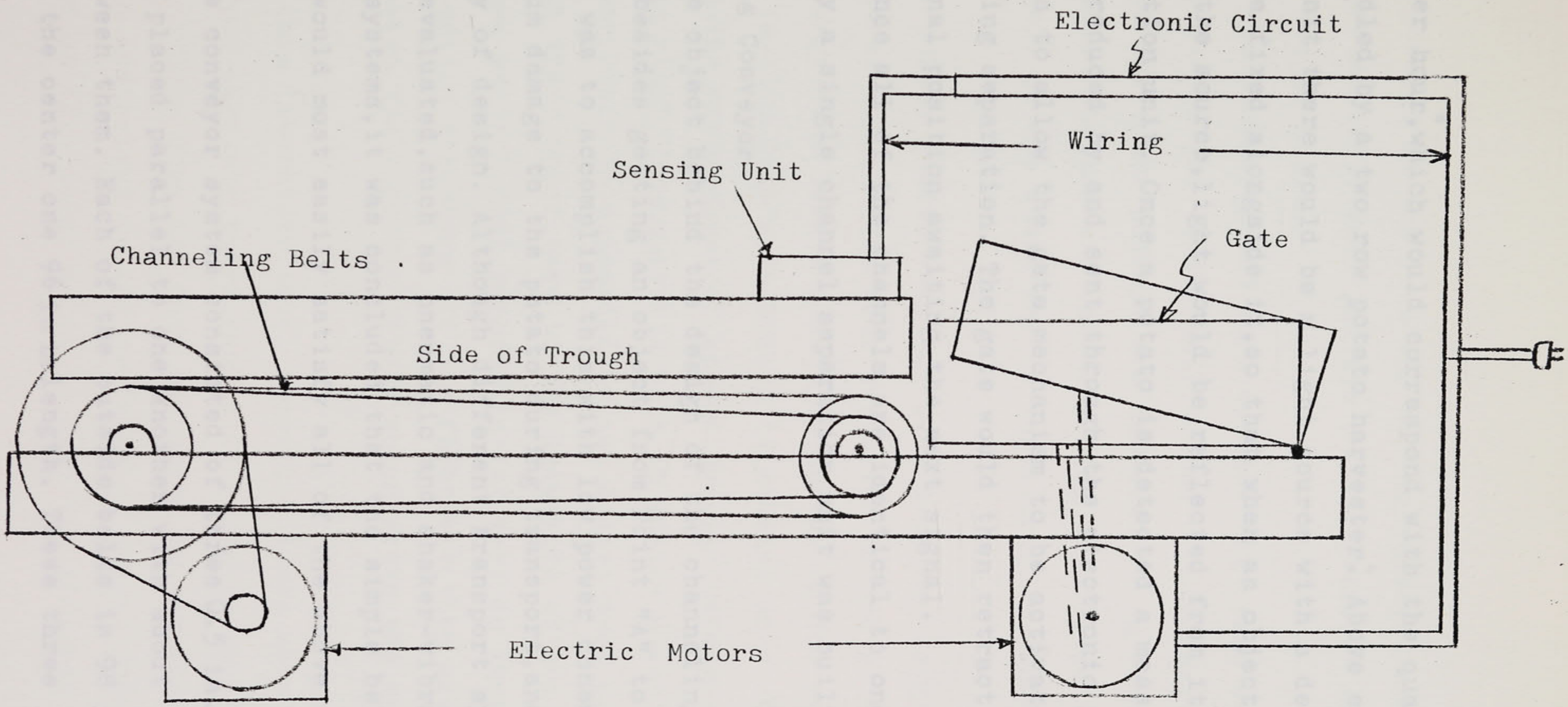


Figure G. View of Channeling Unit

objects per hour*,which would correspond with the quantities handled by a two row potato harvester[4]. Above each channel unit there would be a light source with a detection device fixed alongside it,so that when an object passed under the source,light would be reflected from it to the detection unit. Once a potato is detected a message will be produced by and sent through the electronic circuit so as to allow the gate mechanism to be activated thus causing separation. The gate would then retract to its original position awaiting the next signal.

Since all of the channels are identical to one another,only a single channel separation unit was built.

Channeling Conveyor

The object behind the design of the channeling conveyor,besides getting an object from Point "A" to Point "B" was to accomplish this with low power consumption,minimum damage to the potato during transport,and simplicity of design. Although different transport systems were evaluated,such as pneumatic and shaker-vibrator conveyor systems,it was concluded that the simple belt conveyor would most easily satisfy all of the above objectives.

The conveyor system consisted of three 0.5 in. wide "V" belts placed parallel to one another with about 0.75 in. clearance between them. Each of the outside belts is 98 in long with the center one 96 in in length. These three

* Based on Clods & Stones to Potatoes ratio of 50/50.

belts are powered at the feed end of the conveyor where they run around individual pulleys 3.5 in diameter centered on a common shaft.

At the discharge end each outside belt runs around a 3.5in pulley with the center belt around a 3.0 diameter pulley. The two outer pulleys are fastened to a freely rotating shaft whereas the center pulley is allowed to rotate freely on the shaft and is positioned by handmade washers.

The pulley shafts were cut from a 24 in. long x 0.5 in. diameter steel rod and are each supported by two pillow block bearings. The length center to center of the pulley shafts is 48 in.This axle system is mounted on a narrow rectangular arrangement of spruce 2x4 in^2 on edge,the sides being about 72 in.inlength with an inside width of 4.5in.The structure is supported by two square wood frames attached at their upper ends to the underside of the 2x4 in^2. These frames serve a dual purpose as not only do they elevate the entire structure off the floor but they also serve to house the electric motors which drive the mechanism.

In this laboratory model removable sides were constructed from particle board,each side being about 12 in x 54in and o.75in. thick. They are each supported by two wood posts which are bolted to the rectangular frame. Sides were placed on this model so as to keep the potatoes on track,since there is only one conveyor channel.In actual field application this may not be necessary due to the total width of the conveyor system being 15 channels wide,and in effect might even cause impact damage to the tubers.

The pulley belts themselves rest on a particle-board base board which sits on the rectangular 2 x 4 in^2 frame and occupies the total width between the 2 X 4's and the full length between axles. Since the outer pull-eys at the exit end are larger then the inside pulley it was necessary to use two 0.25 x 1.0 in^2 masonite fillers along the length of the baseboard under the outer belts. These fillers were nailed to the baseboard.

Since the potato itself cannot undergo more than a 6" free fall and subsequent impact without damage there is a clearance between the belts and the baseboard which tends to cushion the fall initiially. However,once the potato has travelled along the belts they no longer sup-port it. It is supported primarily by the Masonite fill-ers which are directly under the belts,consequently they act only to propel the potato.

Electronic Circuit

The proposed electronic circuit actually consists of two circuits,an inner and an outer one. The function of the outer circuit is primarily to receive the reflect-ed light from the potato or stone and transform it into

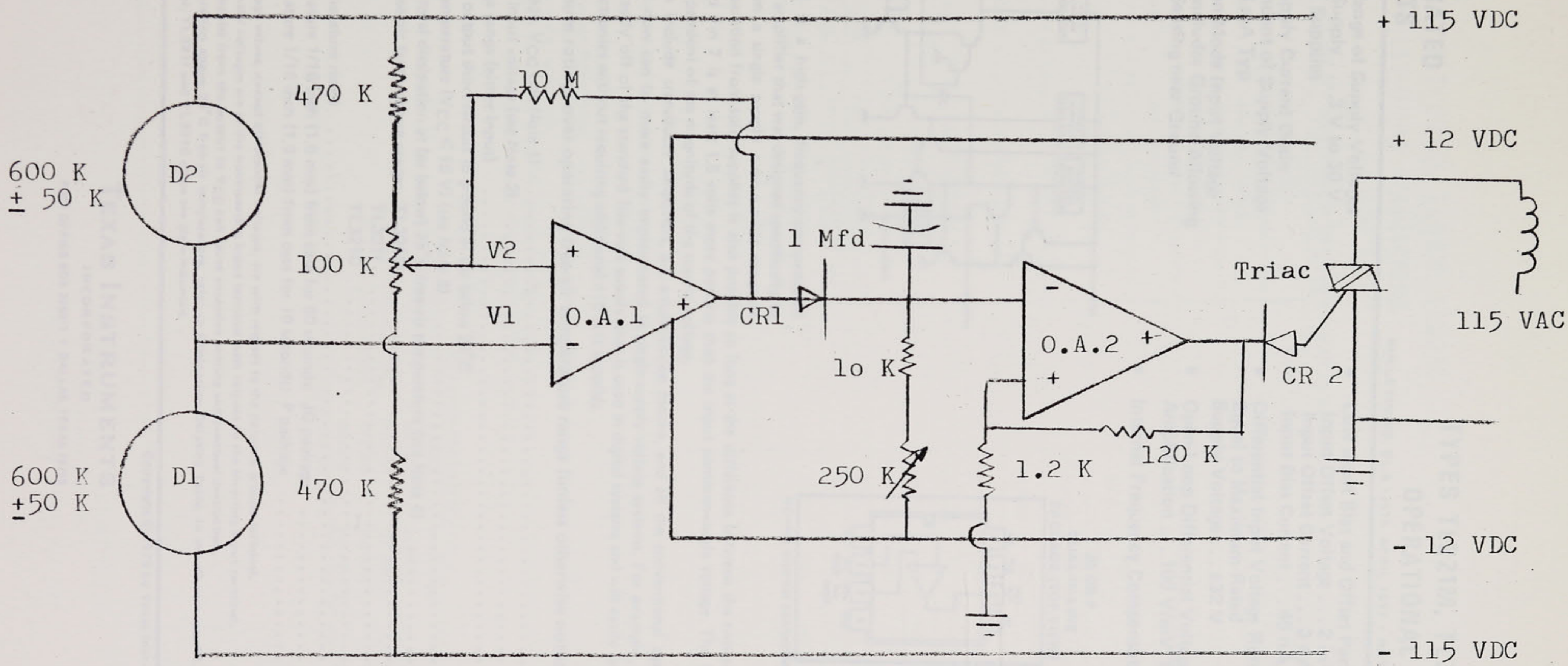


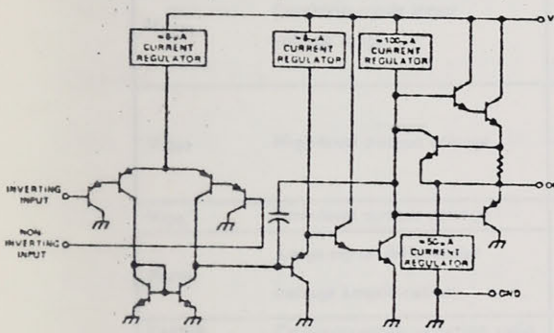
Figure H. Circuit Diagram

TYPES TL321M, TL321I, TL321C OPERATIONAL AMPLIFIERS

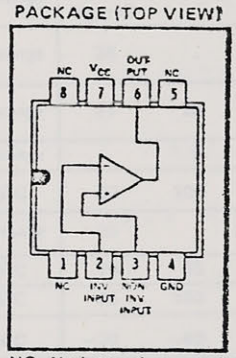
BULLETIN NO. DL-S 12515, APRIL 1977 – REVISED OCTOBER 1979

- Wide Range of Supply Voltages Single Supply . . . 3 V to 30 V or Dual Supplies
- Low Supply Current Drain Independent of Supply Voltage . . . 0.8 mA Typ
- Common-Mode Input Voltage Range Includes Ground Allowing Direct Sensing near Ground
- Low Input Bias and Offset Parameters
  Input Offset Voltage . . . 2 mV Typ
  Input Offset Current . . . 3 nA Typ (TL321M)
  Input Bias Current . . . 45 nA Typ
- Differential Input Voltage Range Equal to Maximum-Rated Supply Voltage . . . ±32 V
- Open-Loop Differential Voltage Amplification . . . 100 V/mV Typ
- Internal Frequency Compensation

schematic



JG OR P
DUAL-IN-LINE
PACKAGE (TOP VIEW)



NC–No internal connection

4

description

The TL321 is a high-gain, frequency-compensated operational amplifier that was designed specifically to operate from a single supply over a wide range of voltages. Operation from split supplies is also possible so long as the difference between the two supplies is 3 volts to 30 volts and Pin 7 is at least 1.5 volts more positive than the input common-mode voltage. The low supply current drain is independent of the magnitude of the supply voltage.

Applications include transducer amplifiers, d-c amplification blocks, and all the conventional operational amplifier circuits that now can be more easily implemented in single-supply-voltage systems. For example, the TL321 can be operated directly off of the standard five-volt supply that is used in digital systems and will easily provide the required interface electronics without requiring additional ±15-volt supplies.

absolute maximum ratings over operating free-air temperature range (unless otherwise noted)

Supply voltage, V_{CC} (see Note 1)	32 V
Differential input voltage (see Note 2)	±32 V
Input voltage range (either input)	−0.3 V to 32 V
Duration of output short-circuit to ground at (or below 25°C free-air temperature ($V_{CC} \leq 15$ V) (see Note 3)	unlimited
Continuous total dissipation at (or below) 25°C free-air temperature (see Note 4)	680 mW
Operating free-air temperature range: TL321M	−55°C to 125°C
TL321I	−25°C to 85°C
TL321C	0°C to 70°C
Storage temperature range	−65°C to 150°C
Lead temperature 1/16 inch (1,6 mm) from case for 60 seconds: JG package	300°C
Lead temperature 1/16 inch (1,6 mm) from case for 10 seconds: P package	260°C

NOTES: 1. All voltage values, except differential voltages, are with respect to the network ground terminal.
2. Differential voltages are at the noninverting input terminal with respect to the inverting input terminal.
3. Short circuits from the output to V_{CC} can cause excessive heating and eventual destruction.
4. For operation above 25°C free-air temperature, refer to Dissipation Derating Table. In the JG package, TL321M chips are alloy-mounted; TL321I and TL321C chips are glass-mounted.

TYPES TL321M, TL321I, TL321C OPERATIONAL AMPLIFIERS

electrical characteristics at specified free-air temperature, V_{CC} = 5 V (unless otherwise noted)

PARAMETER		TEST CONDITIONS†		TL321M, TL321I MIN	TL321M, TL321I TYP	TL321M, TL321I MAX	TL321C MIN	TL321C TYP	TL321C MAX	UNIT
V_{IO}	Input offset voltage	V_O = 1.4 V, V_{CC} = 5 V to 30 V	25°C		2	5		2	7	mV
			Full range			7			9	
I_{IO}	Input offset current	V_O = 1.4 V	25°C		3	30		5	50	nA
			Full range			100			150	
I_{IB}	Input bias current	V_O = 1.4 V, See Note 5	25°C		−45	−150		−45	−250	nA
			Full range			−300			−500	
V_{ICR}	Common-mode input voltage range	V_{CC} = 30 V	25°C	0 to $V_{CC}-1.5$			0 to $V_{CC}-1.5$			V
			Full range	0 to $V_{CC}-2$			0 to $V_{CC}-2$			
V_{OH}	High-level output voltage	V_{CC} = 30 V, R_L = 2 kΩ	Full range	26			26			V
		V_{CC} = 30 V, $R_L \geq$ 10 kΩ	Full range	27	28		27	28		
V_{OL}	Low-level output voltage	$R_L \leq$ 10 kΩ	Full range		5	20		5	20	mV
A_{VD}	Large-signal differential voltage amplification	V_{CC} = 15 V, V_O = 1 V to 11 V, $R_L \geq$ 2 kΩ	25°C	50	100		25	100		V/mV
			Full range	25			15			
CMRR	Common-mode rejection ratio	$R_S \leq$ 10 kΩ	25°C	70	85		65	85		dB
k_{SVR}*	Supply voltage rejection ratio	$R_S \leq$ 10 kΩ	25°C	65	100		65	100		dB
I_O	Output current	V_{CC} = 15 V, V_{ID} = 1 V, V_O = 0 V	25°C	−20	−40		−20	−40		mA
			Full range	−10	−20		−10	−20		
		V_{CC} = 15 V, V_{ID} = −1 V, V_O = 5 V	25°C	10	20		10	20		
			Full range	5	8		5	8		
		V_{ID} = −1 V, V_O = 200 mV	25°C	12	50		12	50		μA
I_{CC}	Supply current	No load, No signal	25°C		0.4			0.4		mA
			Full range			1			1	

*$k_{SVR} = \Delta V_{CC} / \Delta V_{IO}$

†All characteristics are specified under open-loop conditions. Full range is −55°C to 125°C for TL321M, −25°C to 85°C for TL321, and 0°C to 70°C for TL321C.

NOTE 5: The direction of the bias current is out of the device due to the P-N-P input stage. This current is essentially constant, regardless of the state of the output, so no loading change is presented to the input lines.

DISSIPATION DERATING TABLE

PACKAGE	POWER RATING	DERATING FACTOR	ABOVE T_A
JG (Alloy-Mounted Chip)	680 mW	8.4 mW/°C	69°C
JG (Glass-Mounted Chip)	680 mW	6.6 mW/°C	47°C
P	680 mW	8.0 mW/°C	65°C

Also see Dissipation Derating Curves, Section 2.

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Operational Characteristics of Circuit Amplifiers an electrical message whereas the function of the inner circuit is to receive the message,delay it and amplify it so that it may be perceived by other electrical components.

The detectors D-1 and D-2,as indicated on figure H page 23 a, are simply variable resistors whose resistance varies with the intensity of the light which is fed into them. The circuit which was built for the system incorporated two cadmium sulphide detectors with a sensitive area of 0.45 sq.cm.,a minimum dark resistance of 0.5 megaohms and a typical resistance of 100 ohms. These detectors are activated,or turned on,by a 115 volt direct current power source and are linked up in series by two resistors on either side of them,whose resistance is as yet to be determined. This combination of two resistors and two detectors form a bridge system with two 470 kilo-ohm fixed resistors.

Midway between the detectors is attached the negative input to an 8 prong monopolar operational amplifier* with its positive input leading to a 100 kilo-ohm variable resistor. The operational amplifier is powered by a 12 volt direct current power source,and is used to amplify a potential difference when it receives one. In the case where a potato is "sensed" by the detectors D-1 and D-2,the bridge of which they are a part becomes unbalanced,causing a potential difference V-1 and V-2 to appear before the operational amplifier. This positive

* Characteristics described on pages 23b,c.

potential will then be amplified and passed out the positive exit of the operational amplifier to pass through a diode CR-1 unaffected. It then travels to a 1 microfarad 35 volt capacitor which it promptly charges. It then discharges through a 10 Kohm fixed resistor and a 250 Kohm variable resistor. This three component system consisting of a capacitor and two resistors is termed an R-C circuit whose purpose is to delay the relay of an electrical message.

The message then returns to a second operational amplifier whose orientation is altered from that of the first. It enters by the negative input and exits through the positive output to travel through a 100 Kohm fixed resistor only to enter the operational amplifier a second time. This action reverses the charge in the line causing the charge to exit the operational amplifier at its entrance point and flow backwards through a second diode CR-2,unaffected. The message then comes into contact with a Triac. The Triac acts as an electrical gate. When no message reaches it,it acts as an open circuit. When it receives,it acts as a closed circuit so when a potato is sensed the Triac close circuits,allowing current from an outside source to pass through it. This Triac is in effect used as a control to operate an electronically operated gate system,allowing the gate to open or close depending on what the detectors "see".

If a stone or a soil clod is seen by the detectors the bridge system will again become unbalanced with one exception; V-2 will be larger than V-1, causing a negative potential to develop between the lines before the operational amplifier. This will be amplified but will be unable to pass through the diode CR-1, as the diode is set up so as to allow only passage of positive current. The circuit may also be modified so as to reverse the role of the potato and stone.

The Gate System

The gate consists of a 4 in wide by 18 in. long wooden board one end of which is fixed to a hinge which in turned is screwed to one end of the rectangular frame. Masonite sides are attached to the gate in order to avoid spillage of material. On the underside of the gate is attached a mechanical fastener which grips a metal rod. The other end of this rod is bolted to the outer rim of a pulley on the shaft of a $\frac{1}{4}$ hp motor. When the shaft rotates a piston type action is initiated with the gate so that it raises and lowers in phase with the motor thus opening and closing the gate. The motor itself is connected with the Triac so that when a potato is seen by the electronic circuit the Triac closes, allowing power to travel to the motor which pushes the gate into place. Power for the motor is supplied by a standard 110 volt AC wall source. Dampening action for the motor gate system has not yet been attached to the gate to prevent carry-through from the momentum of the motor.

Optical System

The optical devices which were used for this separation unit were very simple optical filters. The purpose of these filters was to supply the detectors with the required wave lengths of light. The bands required were inside of 0.5 and 1.3 microns and from 1.3 microns and higher.

The filters were placed over the conveying system with the detectors right in line behind them so that the reflected light from the potato passes through the filters directly to the detectors. A proposed alternate design utilizes concave optical lenses placed just in front of the filters. This would aid in the concentration of light on the detectors.

Conveyor Power Unit

The power unit used to operate the conveyor system is a $\frac{1}{4}$ hp,1740 rpm electric motor. Since the ideal conveyor speed was found to be approximately 4 ft/s, providing a capacity of about 250,000 items per hour at 15 channels,considerable gearing down of the motor had to be established. This was achieved by using a 12" diam. pulley on the shaft at the drive end of the conveyor with

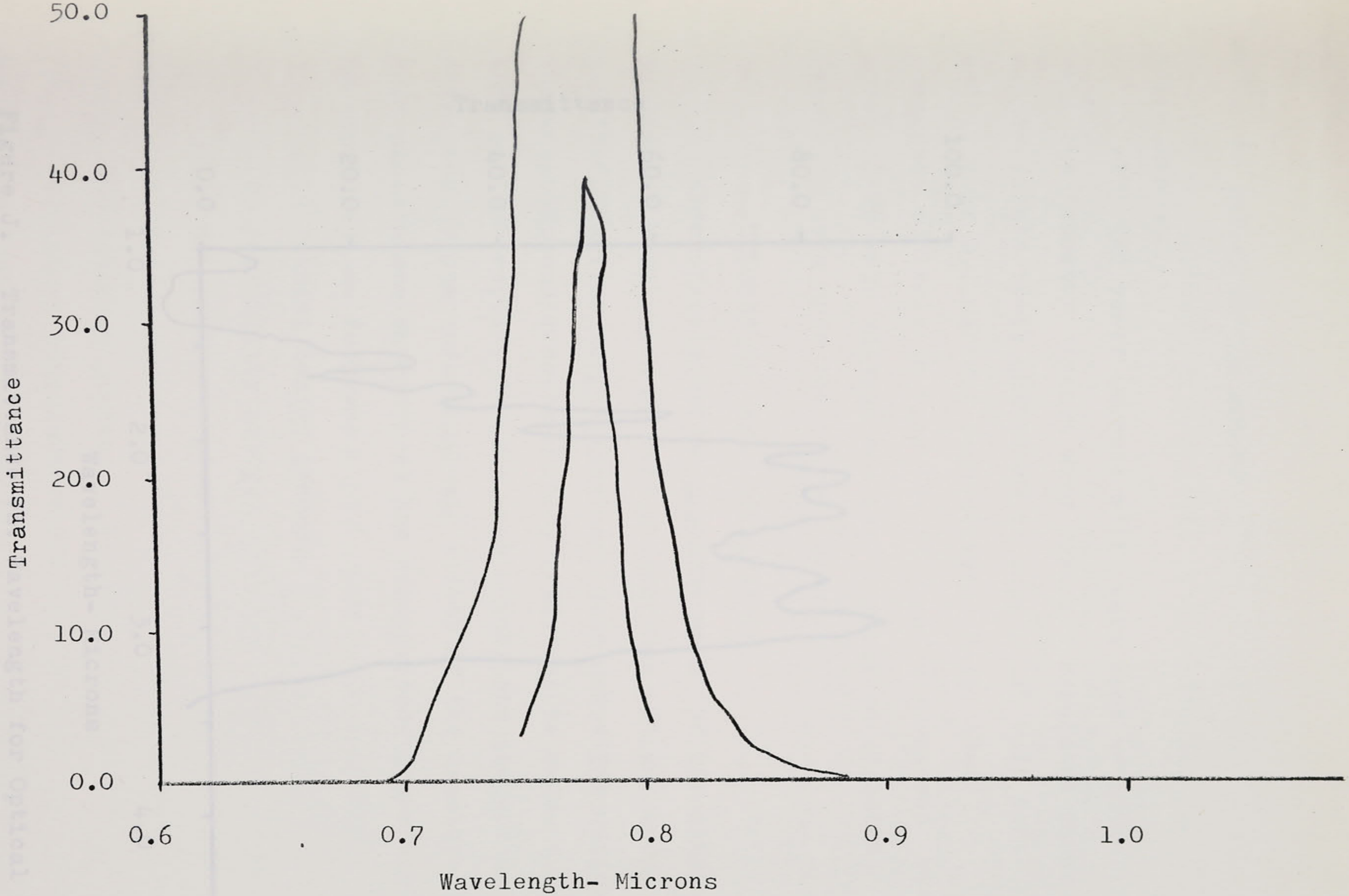


Figure I. Transmittance vs. Wavelength for Optic Filter #1.

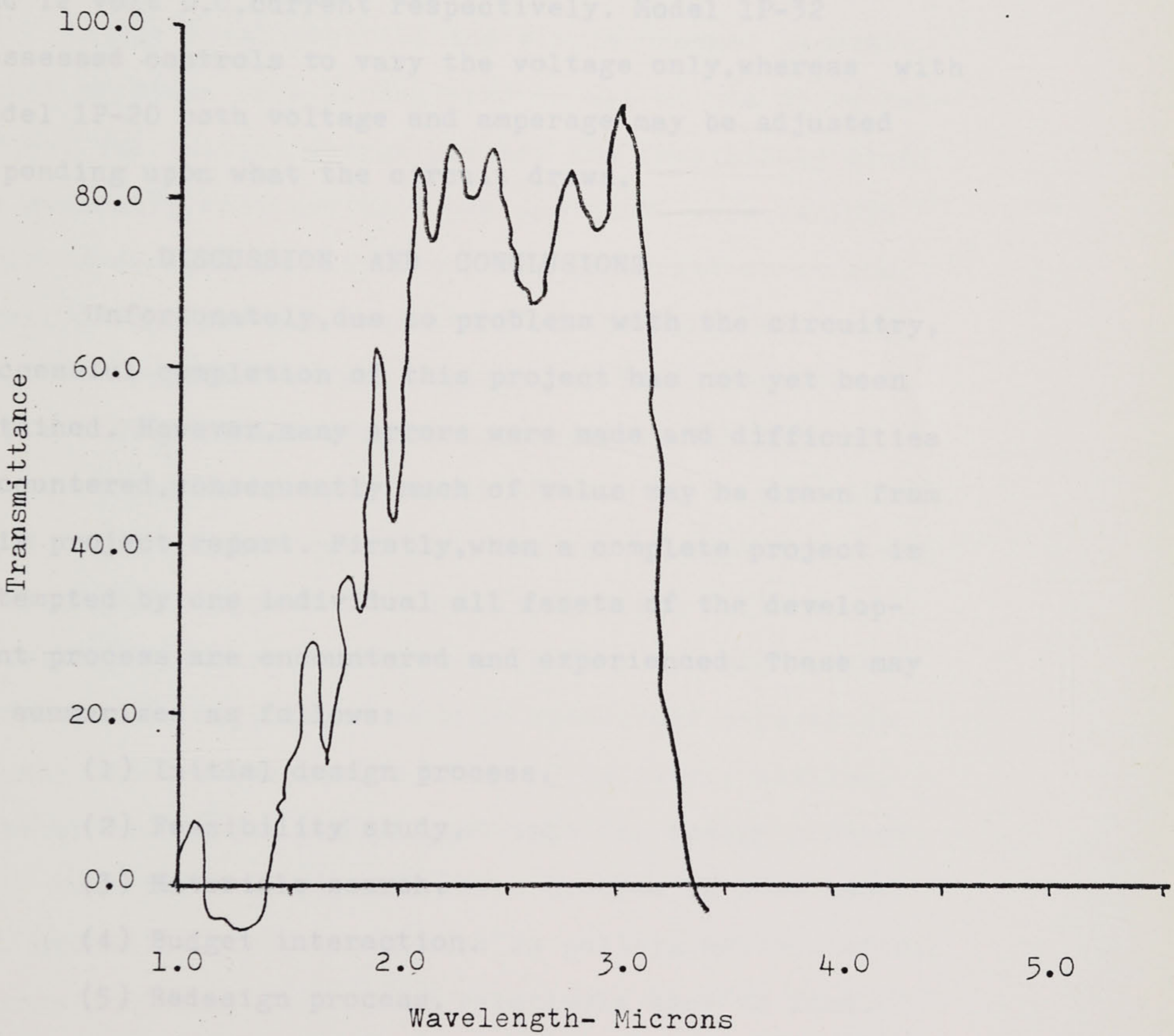


Figure J. Transmittance vs. Wavelength for Optical Filter #2.

a 1.5 in pulley on the motor.

Power Sources

The two power sources which were used to activate the detector circuit were Heathkit regulated power supply Models 1P-32 and 1P-20 to supply 115 volt D.C. and 12 volt D.C.current respectively. Model 1P-32 possessed controls to vary the voltage only,whereas with Model 1P-20 both voltage and amperage may be adjusted depending upon what the circuit draws.

DISCUSSION AND CONCLUSIONS

Unfortunately,due to problems with the circuitry, successful completion of this project has not yet been attained. However,many errors were made and difficulties encountered,consequently much of value may be drawn from this project report. Firstly,when a complete project is attempted by one individual all facets of the development process are encountered and experienced. These may be summarized as follows:

(1) Initial design process.

(2) Feasibility study.

(3) Materials search.

(4) Budget interaction.

(5) Redesign process.

(6) Actual construction.

(7) Errors.

These seven categories are all of equal importance and are interdependent to one another. Ideally,they are basically in order with the exception of the errors category which may enter at any given process and for as many times as an individual will permit. However, practically, many of these categories may be interchanged or may switch positions with any other stage. In other words, there is no steadfast rule.

In the development of the single channel separator unit problems were encountered in all of the above categories. The initial design process and feasibility study were generally combined into one and there were various levels of design. Initially one was concerned about the overall design process, consisting of the mode of conveyance, force application and separation. From there it was again subdivided. For example: conveyance. The type of conveyance had to be established whether it be pneumatic, belt drive or shaker type. When the use of belt drive was established, the type and orientation of the belts were tentatively determined. Belt size, pulley diameters, frame support, potato support, conveyance speed, belt separation and many other details, each being successively smaller, had to be considered and plugged into the design process.

Materials search also was a problem in some aspects. Mechanical components such as pulleys, belts, shafts, bearings and other items were relatively easy to find, once their necessary characteristics were decided on. However, electronic components were a quite different matter. It was found that to purchase even the simplest of electronic components a relatively large background of electrical knowledge was required. For example,to purchase an operational amplifier initially appeared to be an easy chore but actually there were 40 or so different varieties which were available. These included 6 pin,8 pin,10 pin,12 pin,monopolar,bipolar as well as various configurations and voltages etc etc. The list goes on and on. There were similar problems with obtaining detector units. Initially 2 lead sulphide cells were required but these were found to be practically unobtainable,so cadmium sulphide units were substituted. Specifications for these detectors were vague and generally lacked sufficient information for the novice electrician.

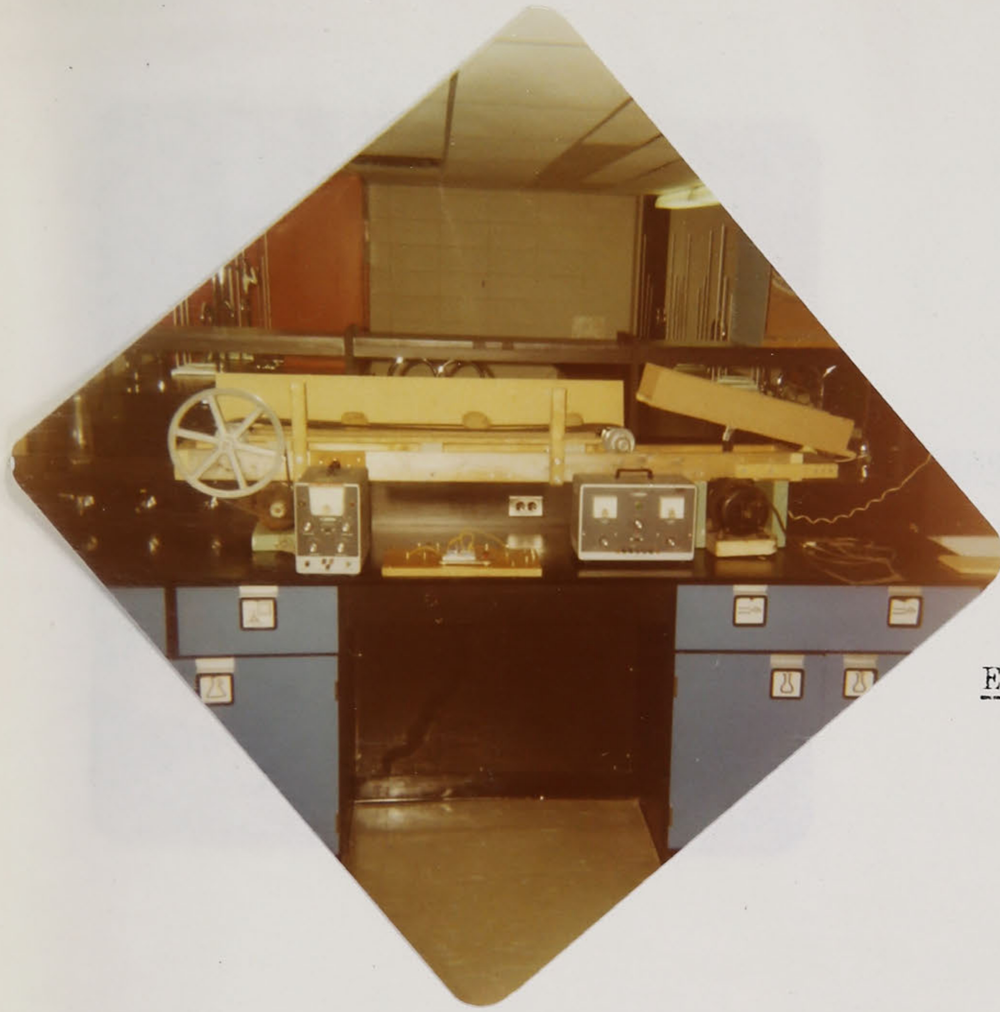
Budgeting was also a problem. Power systems and prime movers are generally far beyond budget restrictions,consequently the ability to make use of what is at one's disposal was frequently brought into play. For example: the two electric motors which were used were both borrowed from existing machines,functional and non-functional. One was from an old laundry machine and the other from a table saw. Originally a solenoid activated pneumatic cylinder was considered for the operation of the gate system,but the "Redesign" factor came into play when the cost of such a device was realized.

The redesign process was incorporated throughout the developmental scheme. Examples have already been mentioned such as the electronic circuit detector from lead sulphide to cadmium sulphide,as well as the method of actuating the gate. the most prominent redesign feature may have been the relocation of the reflectance circuit from a position above the middle belt,concealed in a box, to a place beside the separation unit and enlarged for demonstration and observation purposes.

Finally,actual construction was initiated. At first this process was thought to be of minor detail by the author /designer,however after wrestling with nuts,bolts,nails, drills,pulleys,belts,2 x 4's as well as motor mounts,miscellaneous shafts and bearings and getting them all to combine for a unified movement it was discovered to be no easy job. Alignment of holes,fitting of joints and proper sizing of the wood components all presented difficulties,while the proper positioning of bearings and motors to insure smooth operation of the belts was also quite difficult. Translating the preliminary drawings into a finished mechanism was achieved principally by assuming an initial set of dimensions for the frame and fitting the components individually as work progressed.

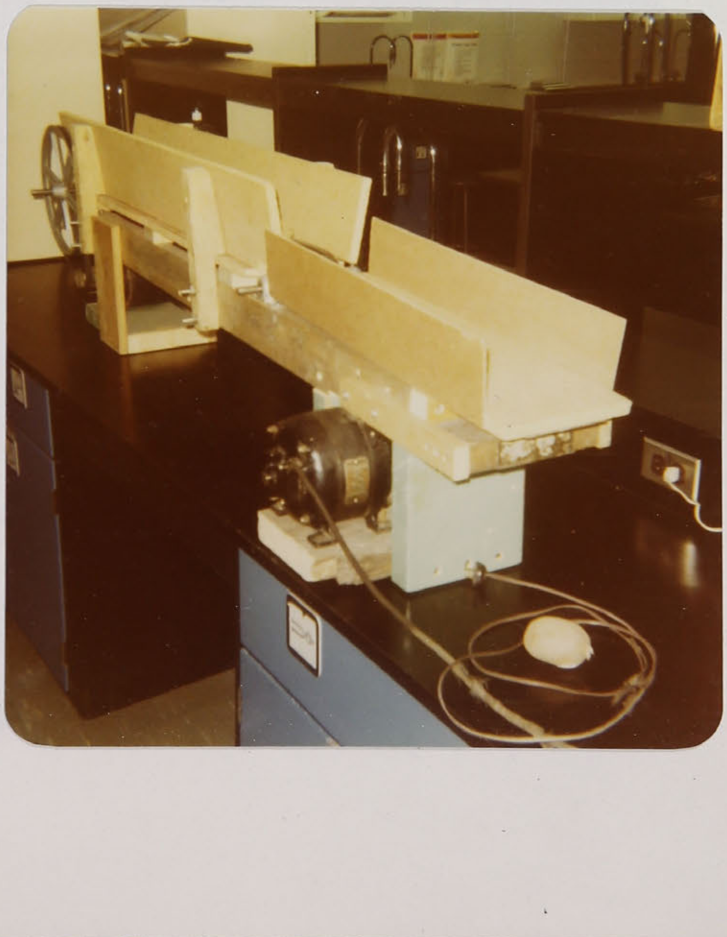
Errors presented another problem,such as one that led me to construct three successive electronic circuits. It was found out that excessive voltage will burn out low value resistors and small grade wire.

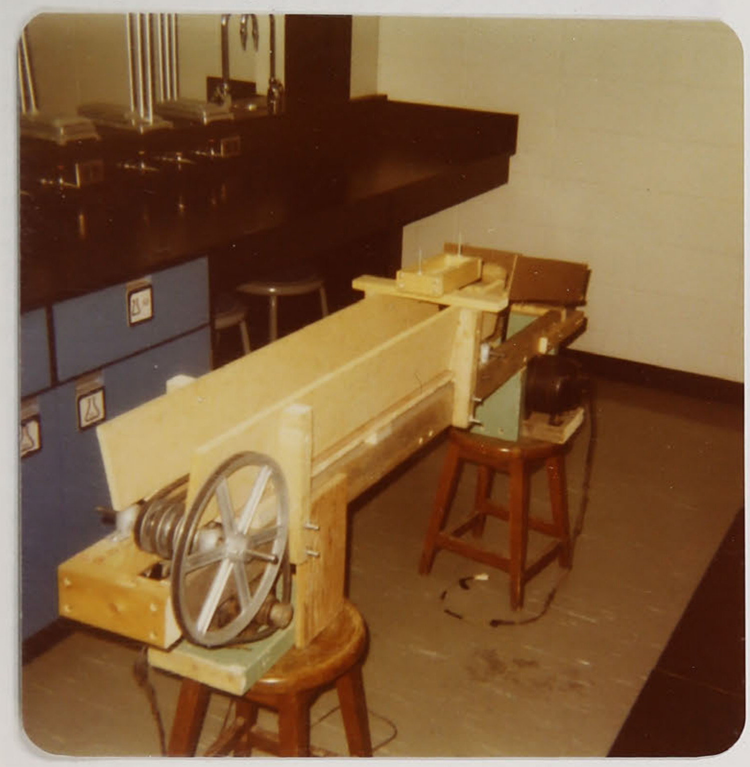
Mechanically the separation unit should work as it was designed to function. It was designed to be simple and effective and these objectives have been satisfactorily met. Problems still remain with the circuitry as circuits rarely per form as they should the first 10 or 20 times around. This circuit has never been completely tested and consequently it must be further debugged.



(1)
AN OVERALL VIEW OF THE SEPARATION UNIT AND THE ELECTRONIC CIRCUIT BELOW, FLANKED BY TWO POWER UNITS

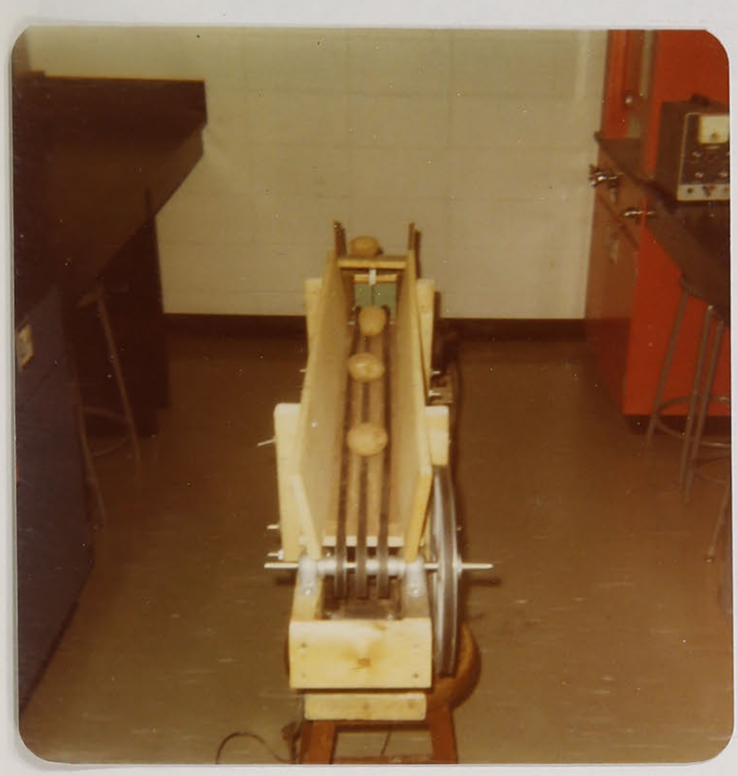
(2)
DISCHARGE END OF THE SEPARATION UNIT REVEALING THE GATE MECHANISM





(3)
FEED END OF UNIT

(4)
VIEW OF THE BELT CONVEYOR SYSTEM WITH GATE OPEN

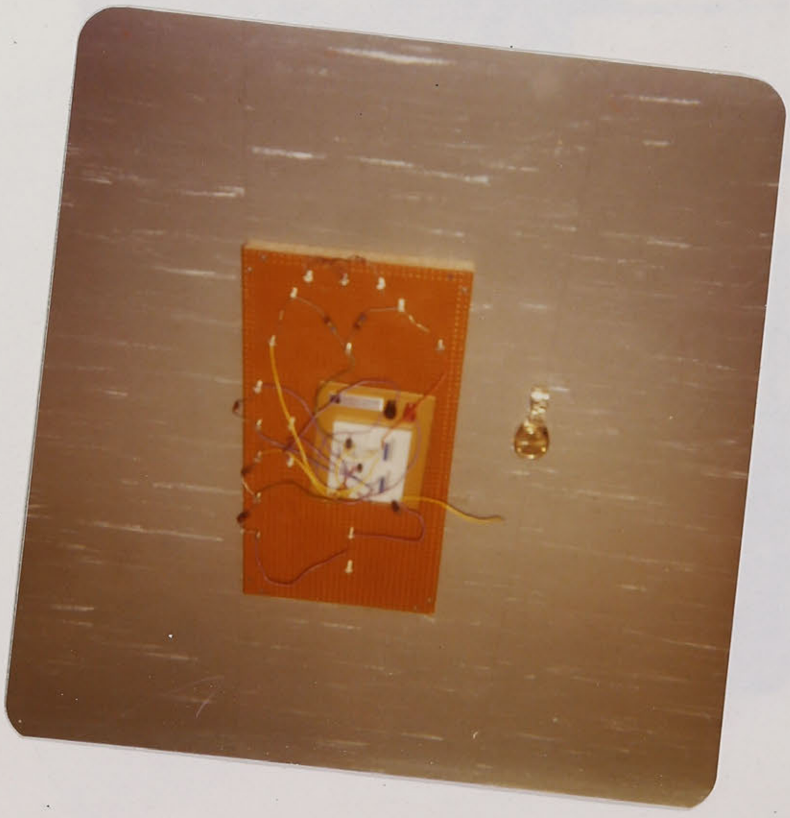


(5)

VIEW OF THE BELT CON-
VEYOR SYSTEM WITH THE
GATE OPEN

(6)

DEMONSTRATION ELE-
CTRONIC CIRCUIT

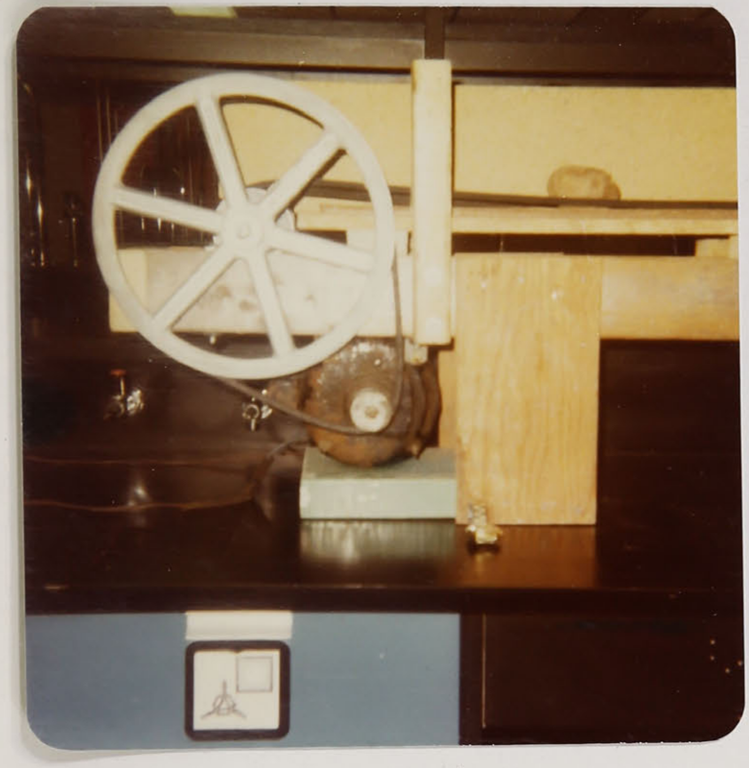


(7)

OPENING ACTION OF GATE SYSTEM

(8)

CLOSING ACTION OF GATE SYSTEM

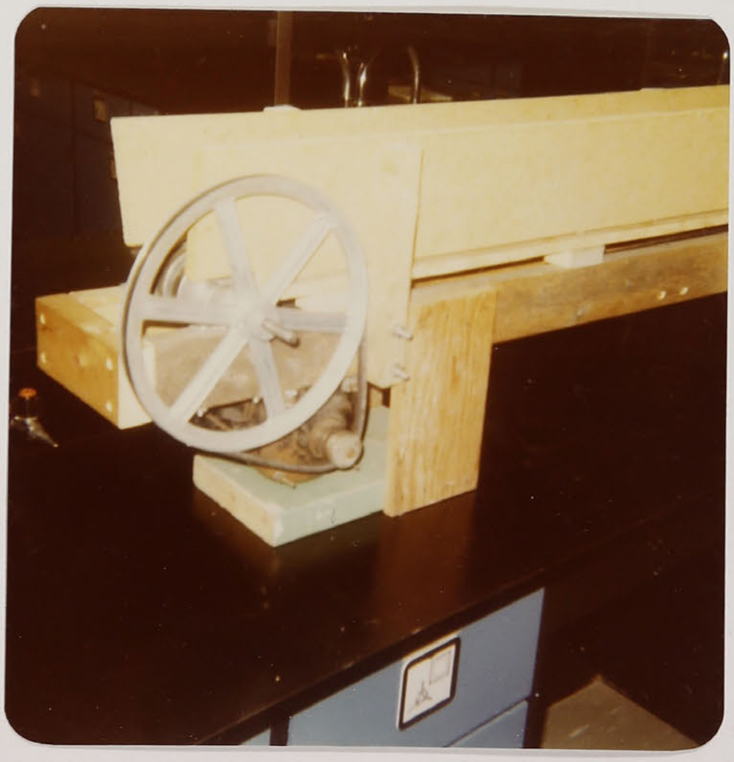


(9)

GEAR DOWN MECHANISM AT FEED END OF CONVEYOR

(10)

GEAR DOWN MECHANISM AT FEED END OF CONV-EYOR



(11)

THE TWO POWER UNITS EMPLOYED: LEFT, 12 V. D.C. RIGHT, 115 V.D.C.

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